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ESTIMATES OF AIR POLLUTANT CONCENTRATIONS AND DEPOSITION DUE TO ELECTRICITY EXPORTS DURING THE PERIOD 1991 - 2006

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ABSTRACT

Ontario Hydro is preparing a submission to the National Energy Board for a license to export electricity during the period 1991-2006. As part of this submission, the social costs of electricity exports need to be estimated. This report provides estimates of the air pollutant concentrations and deposition associated with emissions from the fossil-fuel-fired stations. This information will then be used by private consultants charged with the task of estimating the social costs of exports. Estimates are provided for sulphur and nitrogen species, particulate matter and a number of trace elements.

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ESTIMATES OF AIR POLLUTANT CONCENTRATIONS AND DEPOSITION DUE TO ELECTRICITY EXPORTS DURING THE PERIOD 1991 - 2006

1.0 INTRODUCTION

Ontario Hydro is preparing an application to the National Energy Board for a license to export electricity to the US covering the years 1991-2006. This application will need to consider the social costs incurred in Canada by generating electricity for export. This is so because the Board demands that all costs, including social costs, be recovered.

The calculation of social costs is a multi-step process, involving assessments of:

- the air pollutant concentrations and deposition due to all sources,
- the air pollutant concentrations and deposition due to electricity exports alone,
- the relationship between pollutant dose and receptor response (ie, dose-response relationships), and
- the cost associated with the incremental dose due to electricity exports.

The decision was made to carry out the assessments of air pollutant concentrations and deposition in-house and to use private consultants to estimate dose-response relationships and social costs. This report deals with the in-house assessment of the air pollutant concentrations and deposition associated with emissions from the fossil-fuel-fired stations.

2.0 POLLUTANTS AND EFFECTS

The air pollutants and effects of concern are summarized in Table I. Primary pollutants (ie, SO_2 , NO_x , particulate matter and trace elements) and secondary pollutants (ie, SO_4^{2-} , NO_3^- and acidic deposition) are involved. Some effects are of greatest concern in the vicinity of the power stations (eg, health, building materials), others extend into the medium- to long-range (eg, water quality, terrestrial ecosystems, property values). It is also apparent from the list of effects in Table I that some (eg, terrestrial ecosystems) are more susceptible to impacts during certain seasons of the year. Therefore, it will be necessary to estimate both local and regional impacts of the proposed exports, on a seasonal basis.

TABLE I**AIR POLLUTANTS AND EFFECTS ASSOCIATED WITH THE FOSSIL-FUEL-FIRED STATIONS**

Effect	Pollutant
Health	SO ₂ , SO ₄ ²⁻ aerosol, NO _x , NO ₃ ⁻ aerosol, Particulate Matter, Trace Elements
Water Quality	Acidic Deposition, Trace Elements
Building Materials	SO ₂ , NO _x , Particulate Matter, Acidic Deposition
Terrestrial Ecosystems	SO ₂ , SO ₄ ²⁻ aerosol, NO _x , NO ₃ ⁻ aerosol, Particulate Matter, Acidic Deposition, Trace Elements
Property Values	SO ₂ , NO _x , Particulate Matter, Acidic Deposition

3.0 APPROACH

The air pollutant concentrations and deposition due to all sources are needed in order to determine where, on the dose-response curve, the effect of the incremental additions due to exports should be examined. Two approaches were used to obtain this information:

- environmental monitoring data were compiled and can be used under the assumption that conditions during the period covered by the license application will be similar to the current situation, and
- a variety of pollutant transport and deposition models were used, along with estimates of pollutant emission rates, to calculate the necessary concentrations and deposition.

The air pollutant concentrations and deposition due to electricity exports alone were then calculated by performing a second set of calculations with the above-mentioned models in which the emissions associated with electricity exports were eliminated. The desired air pollutant concentrations and deposition were simply calculated as the difference between the two sets of model runs.

Three pollutant transport and deposition models were used in this study:

- the Ontario Ministry of the Environment's Lagrangian transport model was used to model the long-range transport and deposition of sulphur species, (this is one of the leading long-range transport models currently available for calculations of this type),
- Ontario Hydro's version of Fisher's statistical transport model, was used to model the long-range transport and deposition of nitrogen species, (this model, while not as sophisticated as the Lagrangian model, had to be used because the latter has not been applied to nitrogen species),
- the model prescribed in the Ontario Clean Air Program Discussion Paper was used to model the short-range transport and deposition of SO_2 , NO_x , particulate matter and trace elements.

Details of these models and how they were applied in the current study are given in the following sections of this report.

The emissions data used in the calculations were obtained in a number of ways. Most sources (the exceptions are discussed below) were assumed to continue to operate at the 1980-82 emission level throughout the period covered by the license application. SO_2 and NO_x emissions data for these sources were compiled from inventories provided by the Ontario Ministry of the Environment.

The effect of the Canadian acid gas emissions control program, of which Ontario's Countdown Acid Rain is a component, was taken into account. It was assumed that the program would come into effect in 1994 and lead to emission reductions at Flin Flon, Manitoba; Sudbury (Inco and Falconbridge), and Wawa (Algoma Steel), Ontario; and Noranda, Quebec, in addition to the reductions at Ontario Hydro. This meant that two sets of future emissions had to be considered for sources other than Ontario Hydro's:

- during the period 1991-93 all sources were assumed to emit at the 1980-82 level, and
- during the rest of the period covered by the export license application (1994-2006) the emissions of SO_2 from the above-mentioned Canadian sources were set to (ICF, 1987):

Flin Flon	200 Gg per year
Sudbury	365 Gg per year
Wawa	125 Gg per year
Noranda	272 Gg per year

Ontario Hydro's SO_2 , NO_x and particulate matter emissions were estimated from information provided by Power System Operations Division, and System Planning Division, see Table II. The stepwise application of acid gas emission controls (eg, scrubbers, low-sulphur coal) on Ontario Hydro's system, as well as the various load growth scenarios lead to a relatively large number of emission scenarios.

TABLE II
PROJECTED ONTARIO HYDRO EMISSIONS
ANNUAL EMISSIONS, Gg

		SO ₂		NO _x (as NO)		Particulate Matter	
		Total	Export	Total	Export	Total	Export
Lambton	1991-1993	34.8	18.5	7.8	4.2	1.71	0.91
	1994-1995	18.3	12.2	7.1	4.4	1.55	0.95
	1996-2006L*	12.4	8.6	6.7	4.7	1.44	1.01
	1996-2006M	23.6	5.2	12.8	2.8	2.75	0.61
	1996-2006H	27.9	3.1	15.1	1.7	3.25	0.36
Nanticoke	1991-1993	68.6	21.7	27.5	8.7	4.93	1.55
	1994-1995	70.2	23.0	27.6	9.1	4.95	1.63
	1996-2006L*	21.0	15.1	9.0	6.5	1.25	0.90
	1996-2006M	42.1	17.5	18.0	7.5	2.51	1.04
	1996-2006H	64.1	17.5	27.5	7.5	3.82	1.04
Lakeview	1991-1993	16.7	5.7	4.0	1.4	0.49	0.16
	1994-1995	17.4	5.9	4.3	1.4	0.52	0.17
	1996-2006L*	8.7	6.1	2.2	1.5	0.26	0.18
	1996-2006M	17.8	10.6	4.5	2.7	0.53	0.31
	1996-2006H	36.2	17.5	9.2	4.4	1.07	0.52
Lennox	1991-1993	0.3	0.0	0.1	0.0	0.00	0.0
	1994-1995	0.3	0.0	0.1	0.0	0.0	0.0
	1996-2006L*	0.3	0.0	0.1	0.0	0.0	0.0
	1996-2006M	2.7	1.8	0.8	0.6	0.01	0.0
	1996-2006H	5.3	2.6	1.6	0.8	0.01	0.0
Thunder Bay							
	1991-1993	3.7	0.0	1.1	0.0	0.10	0.0
	1994-1995	4.0	0.0	1.1	0.0	0.11	0.0
	1996-2006L*	4.0	0.4	1.2	0.1	0.11	0.01
	1996-2006M	8.0	0.4	2.3	0.1	0.22	0.01
	1996-2006H	10.4	0.4	3.0	0.1	0.28	0.01
Atikokan	1991-1993	2.2	0.0	0.7	0.0	0.06	0.0
	1994-1995	2.2	0.0	0.7	0.0	0.06	0.0
	1996-2006L*	2.9	0.3	1.0	0.1	0.09	0.01
	1996-2006M	5.8	0.3	1.9	0.1	0.18	0.01
	1996-2006H	6.2	0.3	2.1	0.1	0.19	0.01

*L Low fossil utilization scenario

M Medium fossil utilization scenario

H High fossil utilization scenario

The seasonality of the exports was estimated by System Planning Division as follows:

Winter (Dec, Jan, Feb)	34%
Spring (Mar, Apr, May)	27%
Summer (Jun, Jul, Aug)	19%
Autumn (Sep, Oct, Nov)	20%

Emissions of trace elements were estimated from the coal consumption data and typical emission factors. The latter have been determined in a series of studies conducted by Ontario Hydro (Curtis, 1977), the Canadian Electrical Association (CEA, 1985) and other agencies.

It is clear from the above that fossil-fuel-fired generation for exports will come mainly from Lambton, Nanticoke and Lakeview. The calculations of air pollutant concentrations and deposition associated with exports will thus emphasize these power stations.

4.0 ENVIRONMENTAL MONITORING DATA

A large number of environmental monitoring networks are operated throughout the Province by industry and provincial and federal environmental agencies. Some of the networks are designed to monitor regionally-representative conditions others are intended to map out the local impact of a given source or the conditions in a given urban area. Examples of the most relevant monitoring data are presented here, in the form of annual-average values. Further information, including seasonal-average values, can be provided as needed.

4.1 Regionally-Representative Data

The geographical distribution of the annual-mean pH values of precipitation in 1986 is shown in Figure 1. Southern Ontario is receiving precipitation of pH 4.2-4.3, whereas the values in Central Ontario are 4.3-4.4. Values then increase steadily to the north and west.

The distributions of wet sulphate and nitrate deposition are shown in Figures 2 and 3. The highest deposition rates occur in Southwestern Ontario - 35 kg/ha and 5 kg/ha for SO_4^{2-} and NO_3^- , expressed as N. Deposition rates are 20-35 kg/ha for SO_4^{2-} and 3-5 kg/ha for NO_3^- , expressed as N throughout the rest of Southern and Central Ontario. Values decrease gradually towards the north and west.

The geographical distributions of 1986 annual mean SO_2 , SO_4^{2-} aerosol and NO_3^- aerosol concentrations in Ontario are shown in Figures 4, 5 and 6. Additional data, including data for the rest of Eastern Canada, are shown in Table III. The highest concentrations of all three pollutants are found in Southwestern Ontario - 10, 5 and 1 $\mu\text{g}/\text{m}^3$ for SO_2 , SO_4^{2-} aerosol and NO_3^- aerosol, expressed as N. Concentrations then decrease as one moves away from Southwestern Ontario towards the northeast and north; SO_2 and NO_3^- aerosol at a higher rate than SO_4^{2-} aerosol. The lowest concentrations are found in northern Ontario.

Seasonal data and data for other years are available in diskette form from the authors.

ANNUAL MEAN PH DISTRIBUTION IN 1986

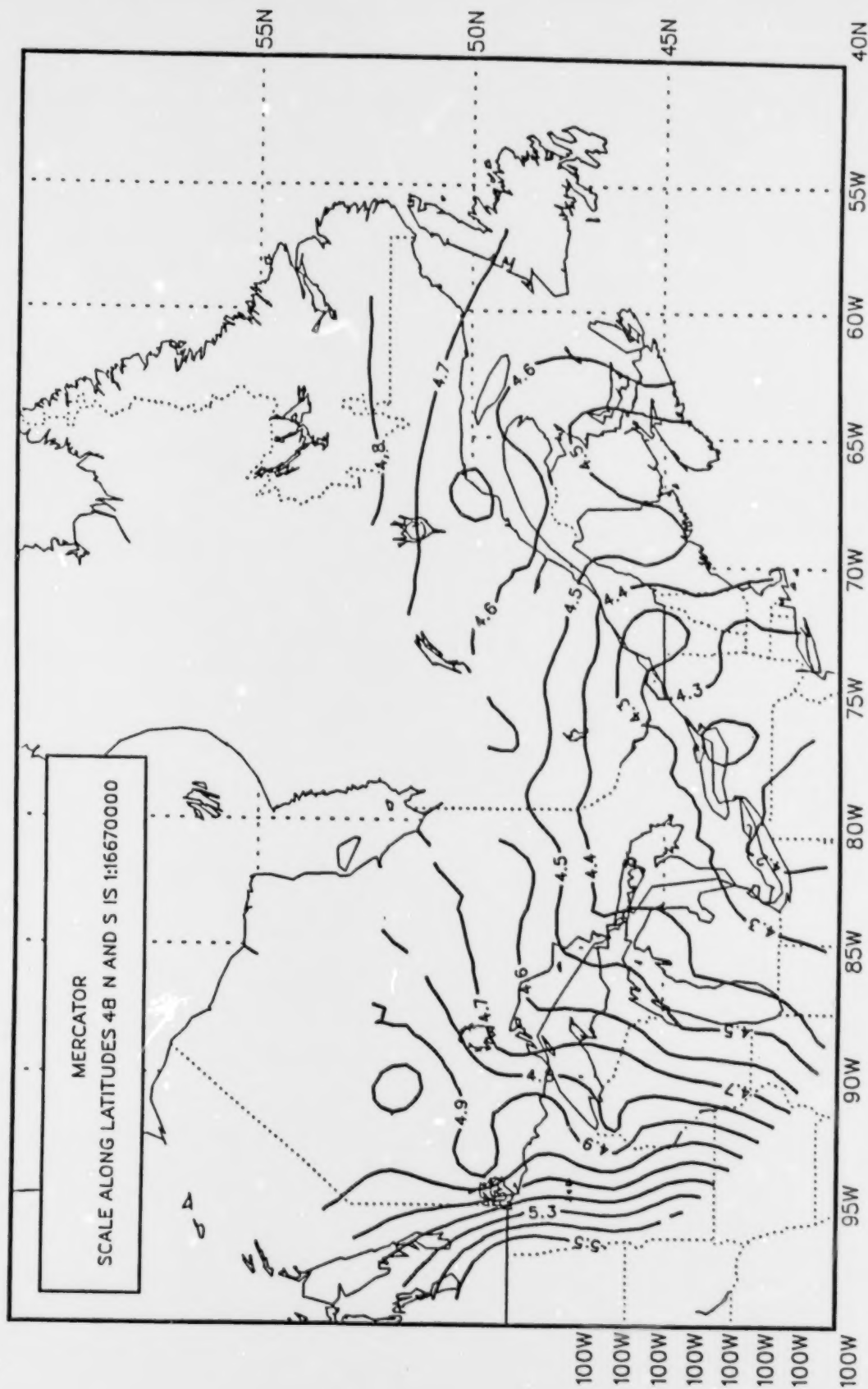


FIGURE 1
ANNUAL MEAN pH DISTRIBUTION IN 1986
(vet, 1989)

WET SO_4^{2-} DEPOSITION IN 1986 (kg/ha) (Vet, 1989)
($1 \text{ kg/ha} = 0.1 \text{ g/m}^2$)

WET N-NO3 DEPOSITION IN 1986 (KG/HA)

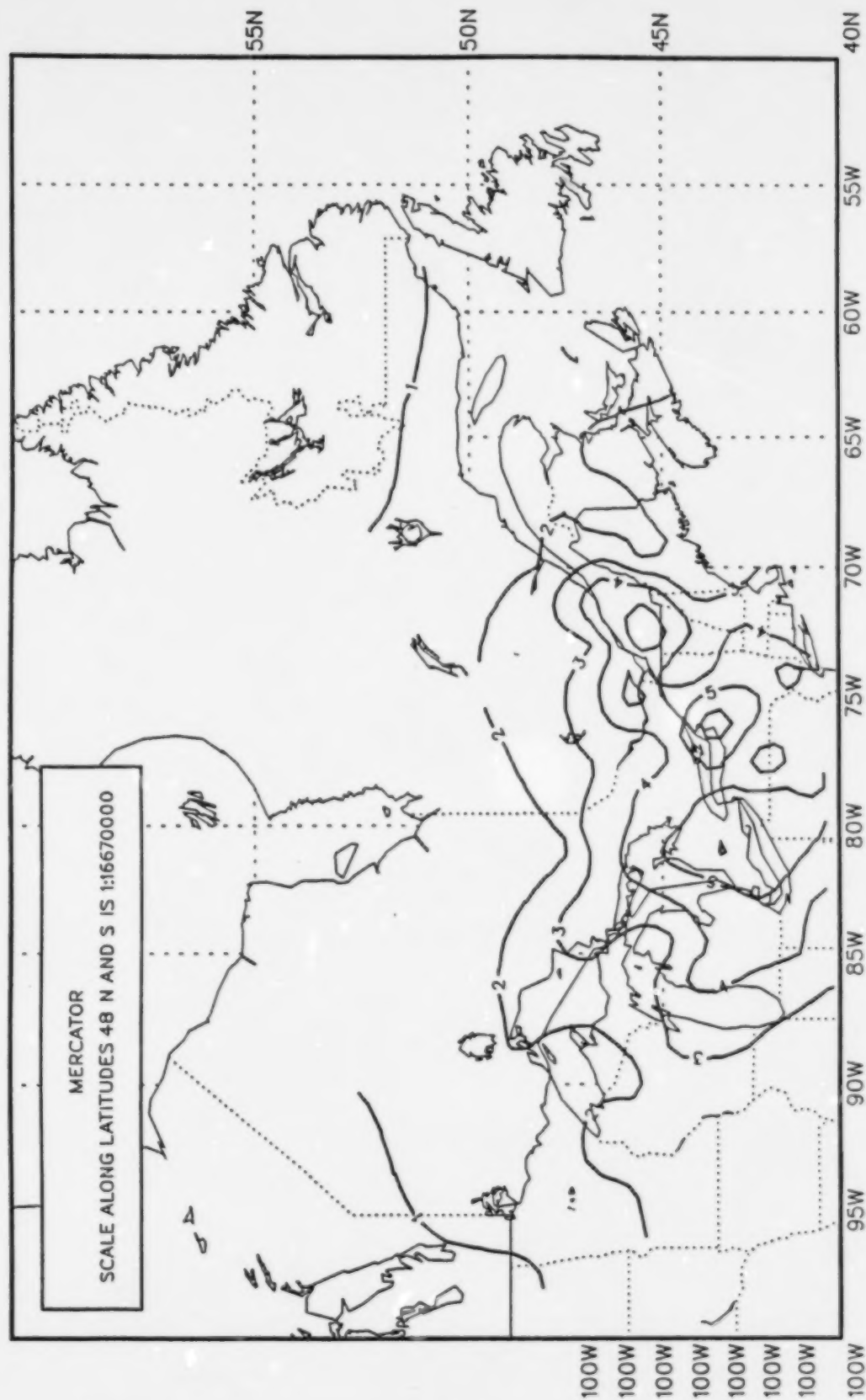


FIGURE 3

WET N-NO₃ DEPOSITION IN 1986 (kg/ha) (Vet 1989)
(1 kg/ha = 0.1 g/m², TO CONVERT N-NO₃ TO NO₃ MULTIPLY BY 4.43)

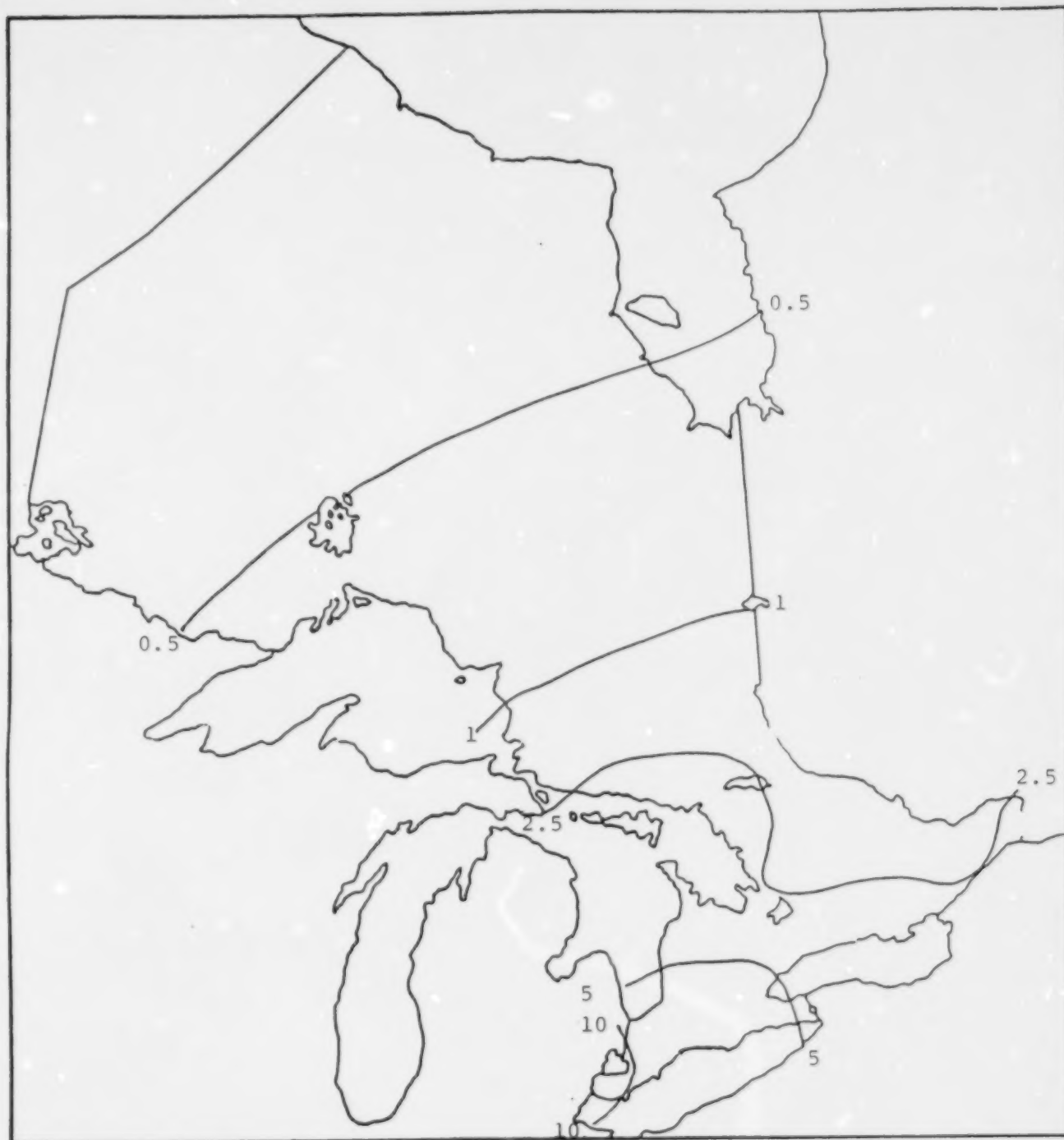


FIGURE 4
SO₂ CONCENTRATION IN 1986 ($\mu\text{g}/\text{m}^3$) (MOE, 1988a)
(TO CONVERT TO ppb MULTIPLY BY 0.372)

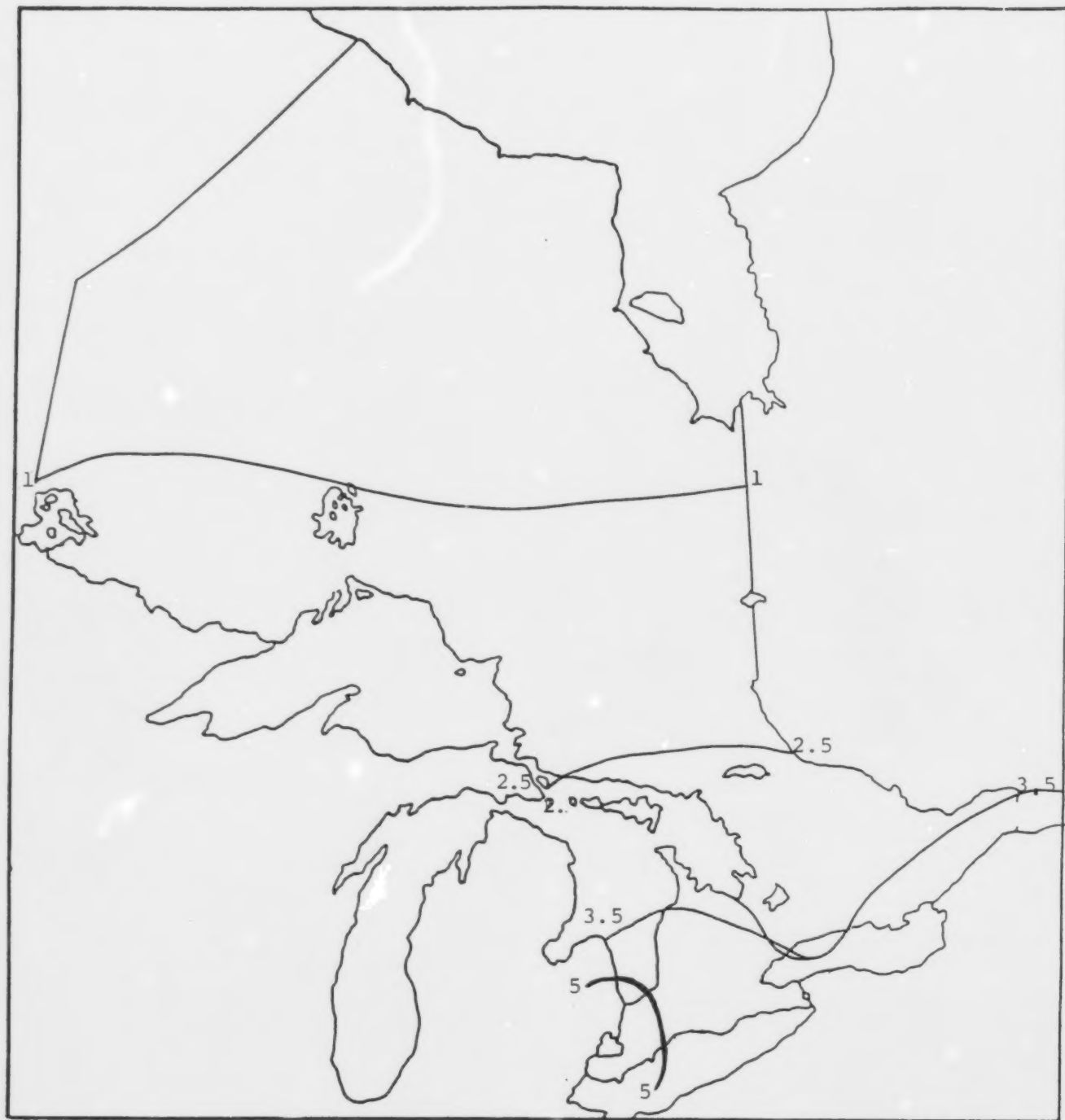


FIGURE 5
 SO_4^{2-} AEROSOL CONCENTRATION IN 1986 ($\mu\text{g}/\text{m}^3$) (MOE, 1988a)

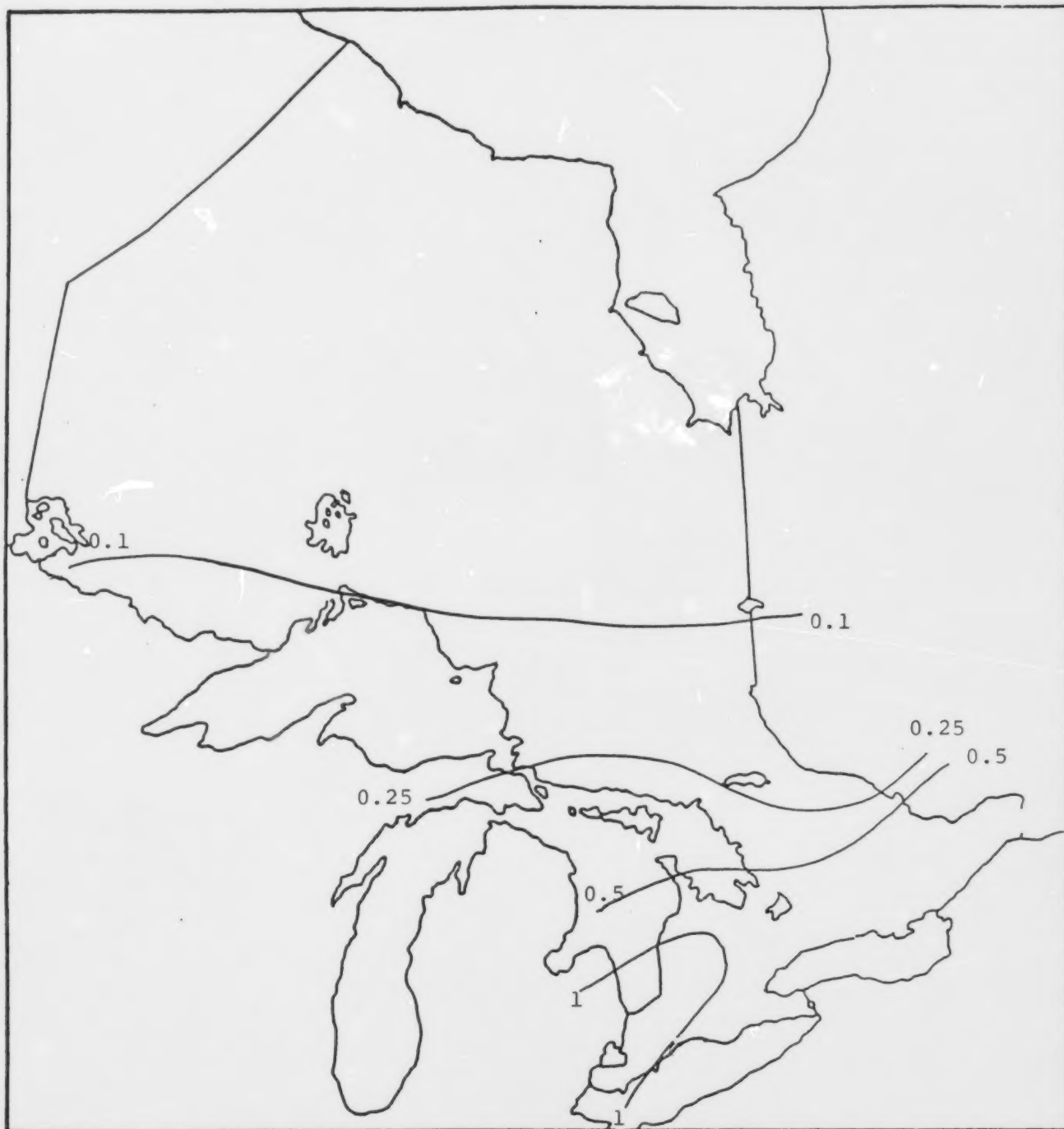


FIGURE 6
 N-NO_3^- AEROSOL CONCENTRATION IN 1986 ($\mu\text{g}/\text{m}^3$) (MOE, 1988a)
 (TO CONVERT N-NO_3^- TO NO_3^- MULTIPLY BY 4.43)

TABLE III

**ANNUAL AIR POLLUTANT CONCENTRATIONS ($\mu\text{g}/\text{m}^3$)
IN EASTERN CANADA (VET, 1989)
Refer to Figure D.1 for Location of Station**

		SO_2	SO_4 aerosol	NO_3 aerosol + HNO_3
ELA, Ontario	1987	0.81	1.42	0.64
	1986	0.68	1.27	0.56
	1985	0.86	1.15	0.40
	1984	1.02	1.88	0.77
	1983	-	1.59	0.59
Algoma, Ontario	1987	2.92	2.52	0.98
	1986	2.90	2.10	0.85
	1985	2.88	2.17	0.73
	1984	3.19	2.71	1.04
	1983	3.17	3.22	0.95
Chalk River, Ontario	1987	4.10	2.93	0.81
	1986	4.05	2.51	0.98
	1985	4.86	2.42	0.78
	1984	3.76	2.96	0.93
	1983	4.99	3.17	0.82
Longwoods, Ontario	1987	9.49	5.13	4.06
	1986	9.19	5.15	4.28
	1985	9.40	4.57	3.98
	1984	9.12	5.43	4.09
	1983	9.11	6.46	4.04
Sutton, Quebec	1987	3.45	3.19	1.65
	1986	3.18	2.85	1.41
Montmorency, Quebec	1987	1.32	1.95	0.47
	1986	2.03	1.68	0.59
	1985	1.38	1.33	0.40
	1984	1.33	1.82	0.44
	1983	-	1.76	0.36
Kejimikujik, Nova Scotia	1987	1.17	2.07	0.49
	1986	1.00	2.05	0.57
	1985	1.37	2.43	0.61
	1984	0.93	2.87	0.63
	1983	-	2.55	0.58

4.2 Locally-Representative Data

Lambton

Some of the air quality monitoring stations operated by Ontario Hydro and the Ontario Ministry of the Environment in the vicinity of Lambton are shown in Figure 7. Mean annual concentrations for a number of pollutants and a number of years are given in Tables IV and V. SO_2 concentrations have decreased in the last 10 years and now (1984-87) range from 4 to 11 ppb. NO_2 , NO and TSP concentrations have also decreased in recent years. Current (1984-87) concentrations in the Sarnia area are 12-23 ppb NO_2 , 6-9 ppb NO and 42-46 $\mu\text{g}/\text{m}^3$ total suspended particulate matter. SO_4^{2-} and NO_3^- aerosol concentrations are somewhat different from the regional distribution of these species shown in Figures 5 and 6. The remaining information refers to a number of trace metals - Pb, Cu, Fe, Mn, Ni, Cr, Cd and V.

Nanticoke

Figure 8 shows the locations of the air quality monitoring stations operated in the vicinity of the Nanticoke power station. Typical results are shown in Tables VI and VII. Annual SO_2 concentrations have varied over the years with little evidence of a systematic trend. Current (1984-87) values are 3-8 ppb, somewhat lower than around Lambton. NO_2 and NO concentrations are now in the range of 5-9 and 4-7 ppb, respectively, significantly lower than around Lambton. Concentrations of total suspended particulate matter are relatively low compared to Lambton, whereas the concentrations of SO_4^{2-} and NO_3^- aerosol are consistent with the regional patterns of Figures 5 and 6. Only a limited amount of data is available on trace metals.

Lakeview

The location of the air quality monitoring stations operated in the vicinity of Lakeview is shown in Figure 9. Typical results are given in Tables VIII, IX and X. SO_2 concentrations have decreased since the late 1970's and now (1984-87) range from 4 to 8 ppb. These values are similar to those obtained at Nanticoke and lower than at Lambton. NO_2 and NO concentrations are relatively high as would be expected given the urbanization around Lakeview. Concentrations of total suspended particulate matter have also decreased since the late 1970's and stand at 50-60 $\mu\text{g}/\text{m}^3$ (geometric mean).

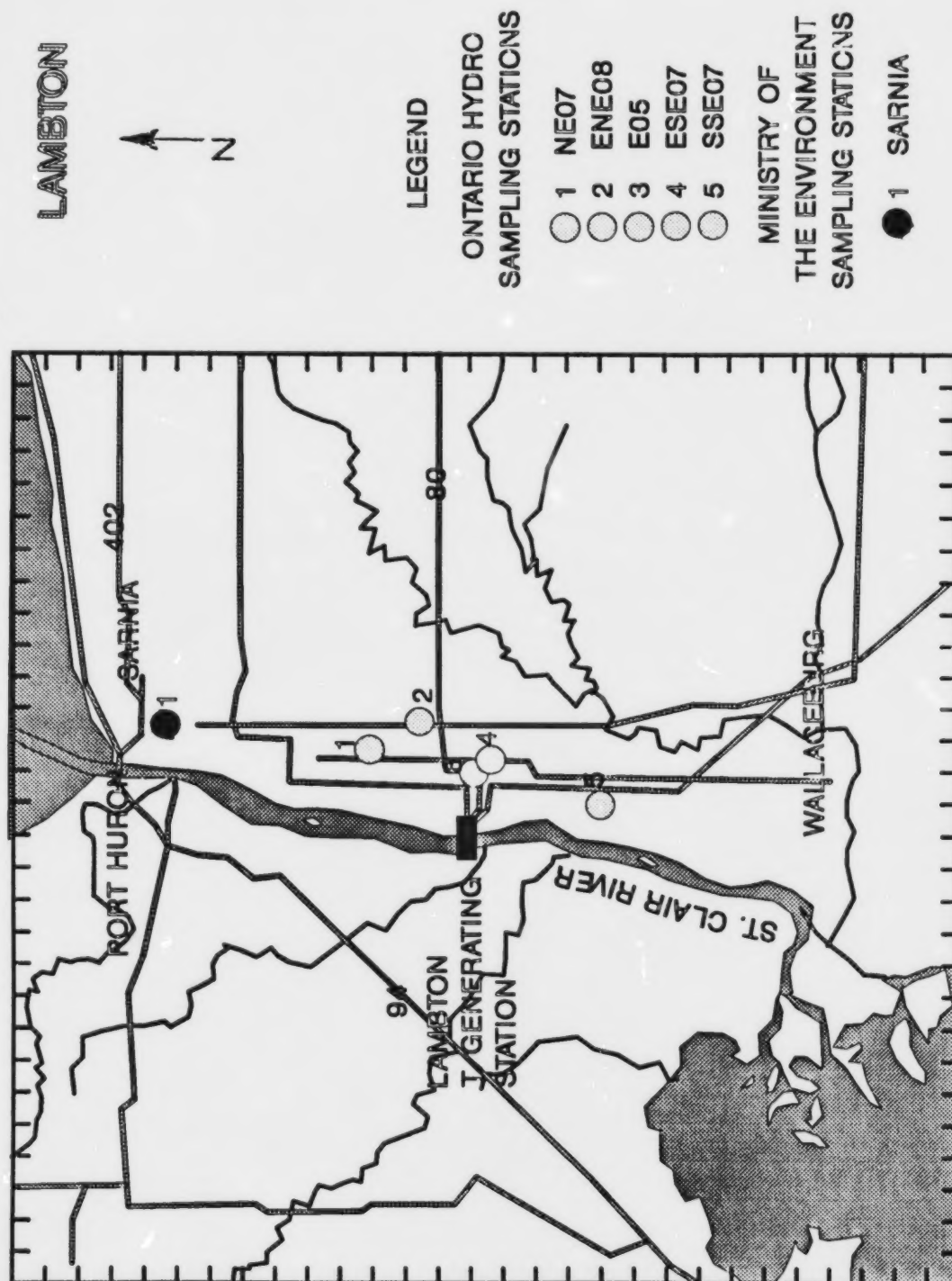


Figure 7

TABLE IV

**ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb)
AROUND LAMBTON (OH, 1988a)**

	<u>NE07</u>	<u>ENE08</u>	<u>E05</u>	<u>ESE07</u>	<u>SSE07</u>
1987	5	5	5	5	4
1986	6	4	6	6	4
1985	12	3	6	6	4
1984	7	7	8	7	7
1983	8	9	6	5	6
1982	9	10	8	5	3
1981	8	8	8	8	6
1980	8	7	6	6	5
1979	8	9	6	7	6
1978	9	7	9	8	6
1977	12	11	12	9	10
1976	9	10	12	7	10
1975	15	7	11	12	10

TABLE V
ANNUAL AVERAGE CONCENTRATIONS OF SEVERAL
POLLUTANTS AT SARNIA (MOE STATION 14064), ONTARIO (MOE, 1988b)

	SO ₂	NO ₂	NO	TSP	SO ₄ ²⁻	NO ₃ ⁻	Pb	Cu	Fe	Mn	Ni	Cr	Cd	V
	<-----ppb----->				<-----μg/m ³ (geometric mean)----->									
1987	7	12	6	42	7.3	2.7	0.0	0.14	0.4	0.018	0.006	0.005	0.001	0.010
1986	8	21	9	45	7.0	2.7	0.1	0.13	0.4	0.014	0.002	0.004	0.000	0.008
1985	11	19	7	46			0.1							
1984	9	23	8	45			0.1							
1983	10	20	10	59			0.2							
1982	12	22	9	58			0.1							
1981	14	15	14	62			0.1							
1980	13	22	10	76			0.1							
1979	17	19	17	66			0.2							
1978	16	31	19	80			0.1							
1977	23	27	17	76			0.6							

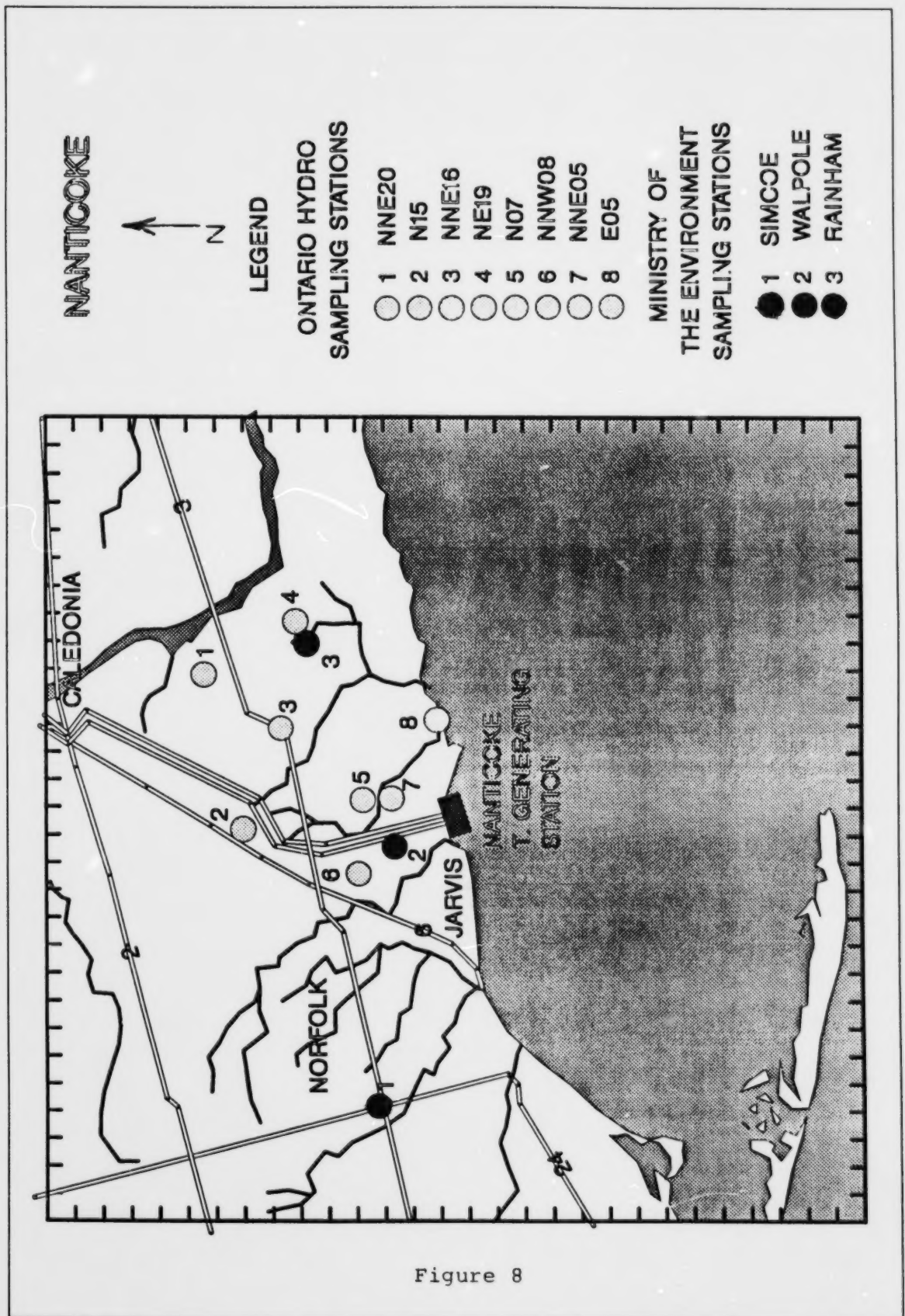


TABLE VI**ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb)
AROUND NANTICOKE (OH, 1988b)**

	<u>NO7</u>	<u>N15</u>	<u>NNE05</u>	<u>NNE16</u>	<u>NNE20</u>	<u>NE19</u>	<u>E05</u>	<u>NNW08</u>
1987	5	-	6	6	-	4	-	4
1986	6	4	6	6	5	4	4	4
1985	6	4	6	5	4	4	5	4
1984	7	5	8	6	6	5	6	3
1983	5	4	6	5	4	4	5	5
1982	5	5	7	7	6	5	4	4
1981	4	4	7	6	5	5	4	4
1980	4	3	4	6	5	5	6	4
1979	6	5	6	8	5	6	7	5
1978	6	6	7	8	5	7	8	6
1977	6	9	-	7	-	7	7	7
1976	6	7	-	7	-	6	7	5
1975	6	5	-	5	-	4	9	4
1974	9	7	-	5	-	5	-	0

TABLE VII

**ANNUAL AVERAGE CONCENTRATIONS OF SEVERAL POLLUTANTS
AT SIMCOE (MOE STATION 22071), WALPOLE (MOE STATION 22904)
AND RAINHAM RD (MOE STATION 22907) (MOE 1988b)**

	SO ₂	NO ₂	NO	TSP	SO ₄ ²⁻	NO ₃	Pb	Cu	Fe	Mn	Ni	Cr	Cd	V
	<-----Simcoe----->			<-----Walpole----->			<-----Rainham Rd----->							
	<-----ppb----->			<----->			μg/m ³ (geometric mean)----->							
1987	3	5	5	32	8.9	3.4	0.0	0.80	2.5	0.093	0.004	0.006	0.000	0.009
1986	3	5	7	33	7.7	2.5	0.0	-	-	-	-	-	-	-
1985	5	6	4											
1984	4	9	5											
1983	3	9	2											
1982	4	10	2											
1981	4	14	2											
1980	7	12	1											
1979	9	10	3											
1978	7	14	5											
1977	11	12	9											
1976														
1975														
1974														

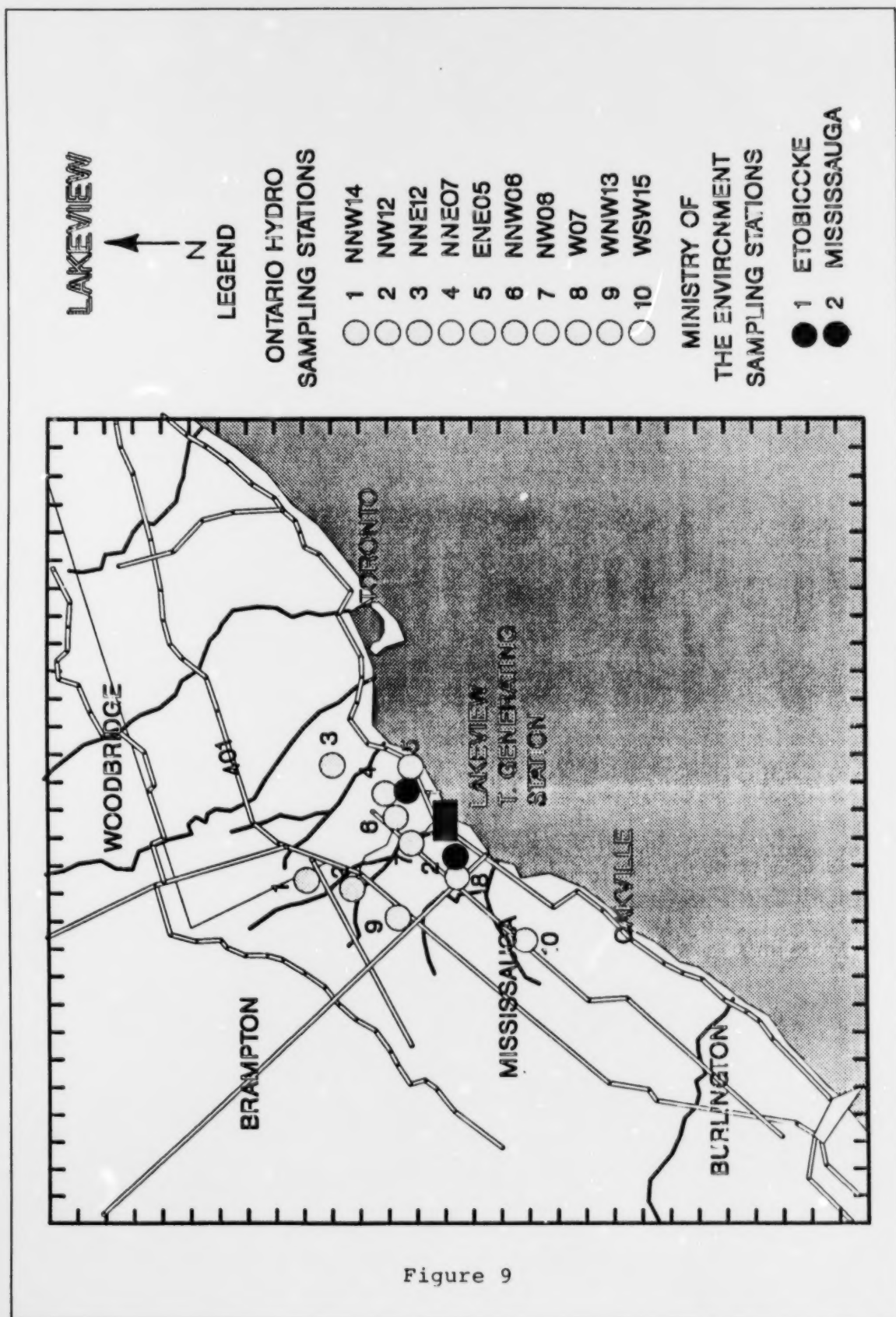


TABLE VIII

ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb)
AROUND LAKEVIEW (OH, 1988c)

	<u>NNE07</u>	<u>NNE12</u>	<u>ENE05</u>	<u>WSW15</u>	<u>W07</u>	<u>WNW13</u>	<u>NW06</u>	<u>NW12</u>	<u>NNW06</u>	<u>NNW14</u>
1987	7	-	6	-	5	4	5	-	-	-
1986	5	-	5	4	6	4	4	5	5	-
1985	7	-	6	5	6	5	6	5	5	-
1984	7	8	6	6	7	5	7	5	6	6
1983	5	7	5	5	6	4	6	6	5	5
1982	6	4	5	3	6	4	6	4	6	3
1981	7	6	7	5	6	5	6	5	6	4
1980	7	5	8	3	7	3	6	3	6	4
1979	4	-	9	-	9	-	7	-	7	-
1978	10	-	9	-	8	-	7	-	8	-
1977	14	-	11	-	10	-	12	-	14	-
1976	13	-	10	-	7	-	10	-	11	-
1975	8	-	6	-	7	-	9	-	8	-
1974	9	-	12	-	9	-	-	-	13	-

TABLE IX

**ANNUAL AVERAGE CONCENTRATIONS OF SEVERAL POLLUTANTS
AT ETOBICOKE (MOE STATION 35033), ONTARIO (MOE, 1988b)**

	SO ₂	NO ₂	NO	TSP	SO ₄ ²⁻	NO ₃ ⁻	Pb	Cu	Fe	Mn	Ni	Cr	Cd	V
	<-----ppb----->			<-----μg/m ³ (geometric mean)----->										
1987	5	32	61	62	8.2	2.8	0.1	0.07	0.8	0.058	0.005	0.006	0.001	0.006
1986	5	27	31	61	8.7	3.8	0.2	0.08	0.7	0.035	0.003	0.006	0.000	0.005
1985	7	26	27	58	7.7	3.0	0.2	0.16	0.8					
1984	7	24	26	59	9.3	3.7	0.2	0.10	0.8					
1983	6	21	26	53	8.8	3.3	0.3	0.12	0.7					
1982	6	21	27	74	11.3	4.9	0.3	0.08	0.7					
1981	8	22	26	91	12.1	4.9	0.2	0.23	1.1					
1980	8	18	19	83	13.8	4.6	0.1	-	-					
1979	10	22	27	84	12.9	4.1	0.2	0.08	1.5					
1978	10	25	26	71	10.8	4.3	0.5	0.22	1.3					
1977	11	22	32	65	8.6	2.4	0.5	0.23	1.1					

TABLE X

**ANNUAL AVERAGE CONCENTRATIONS OF SEVERAL POLLUTANTS
AT MISSISSAUGA (OME STATIONS 46110, 46025), ONTARIO (MOE, 1988b)**

	SO ₂	NO ₂	NO	TSP	SO ₄ ²⁻	NO ₃	Pb	Cu	Fe	Mn	Ni	Cr	Cd	V
	<-----46110----->			<-----46025----->										
	<-----ppb----->			<-----µg/m ³ (geometric mean)----->										
1987	9	25	30	56	9.2	2.9	0.1	-	-	-	-	-	-	-
1986	7	26	32	53	7.1	3.0	0.2	0.08	0.5	0.026	0.004	0.006	0.000	0.006
1985				55	7.1	3.5	0.2	0.08	0.8					
1984				68	10.7	3.8	0.3	0.10	0.9					
1983				60	10.0	4.1	0.3	0.14	0.9					
1982				62	9.5	4.0	0.3	0.23	0.8					
1981				73	10.3	3.5	0.4	0.37	1.2					
1980				70	10.3	3.1	0.3	0.33	1.2					
1979				70	8.9	3.6	0.4	0.20	1.2					
1978				58	9.0	3.3	0.5	0.44	1.0					
1977				66	8.3	2.3	0.5	0.13	1.1					

5.0 LONG-RANGE TRANSPORT OF SULPHUR - PREDICTIONS FROM A LAGRANGIAN TRANSPORT MODEL

The applicability of the environmental monitoring data presented in Section 4.0 is limited in two ways:

- the data represent past conditions, not necessarily the conditions during the period covered by the license application, and
- the data cannot be used to establish what fraction of the observed concentrations and deposition is due to specific sources or types of operations (eg, exports.)

To overcome these difficulties, one needs to resort to atmospheric transport and deposition models.

In the present study, we employed the Lagrangian trajectory puff model developed by the Ontario Ministry of the Environment to predict concentrations and deposition of sulphur dioxide and sulphate on a regional scale. A description of the model is given in Appendix A. As input, we used the meteorological data provided by the Ontario Ministry of the Environment for the year 1982. The data included surface pressure and precipitation fields for North America east of the Rockies at six-hour intervals. A total of 182 area sources of SO_2 emissions, distributed over the region, were included in the model. The model domain and locations of the emission sources are shown in Figure 10.

As discussed in Section 3.0, three sets of emissions data, one covering the period 1991-1993, another the period 1994-1995, and the third the period 1996-2006 with low, medium and high fossil-fuel usage scenarios, were compiled from information provided by the Ontario Ministry of the Environment, the impact of acid rain legislature in Eastern Canada, and Ontario Hydro's estimates of fossil-fuel-fired generation, with and without exports.

Model predictions for the entire grid area and for seven acid-sensitive receptor regions were examined in the study. The acid-sensitive regions coincide with those used by Moroz (1982). The regions are acid-sensitive by complying with the following criteria: lake-area location; pH value less than 6.3; conductivity less than 3 mS/m and Gran alkalinity less than 300 $\mu\text{eq/L}$ (Torrenueva, 1980). The seven regions are the Lakehead, Algoma, Muskoka and Haliburton areas in Ontario, small areas in Minnesota and Northern Michigan and the Adirondacks area of New York as shown in Figure 11.

The model was run with each of the emission scenarios. Ground-level concentrations, dry deposition, and wet deposition of SO_2 and SO_4^{2-} were calculated on a monthly basis and then aggregated into yearly and seasonal totals. Annual results for the medium scenario in the 1996-2006 period are shown in Figures 12-19. Seasonal data and data for the other emission scenarios are available in diskette form from the authors.

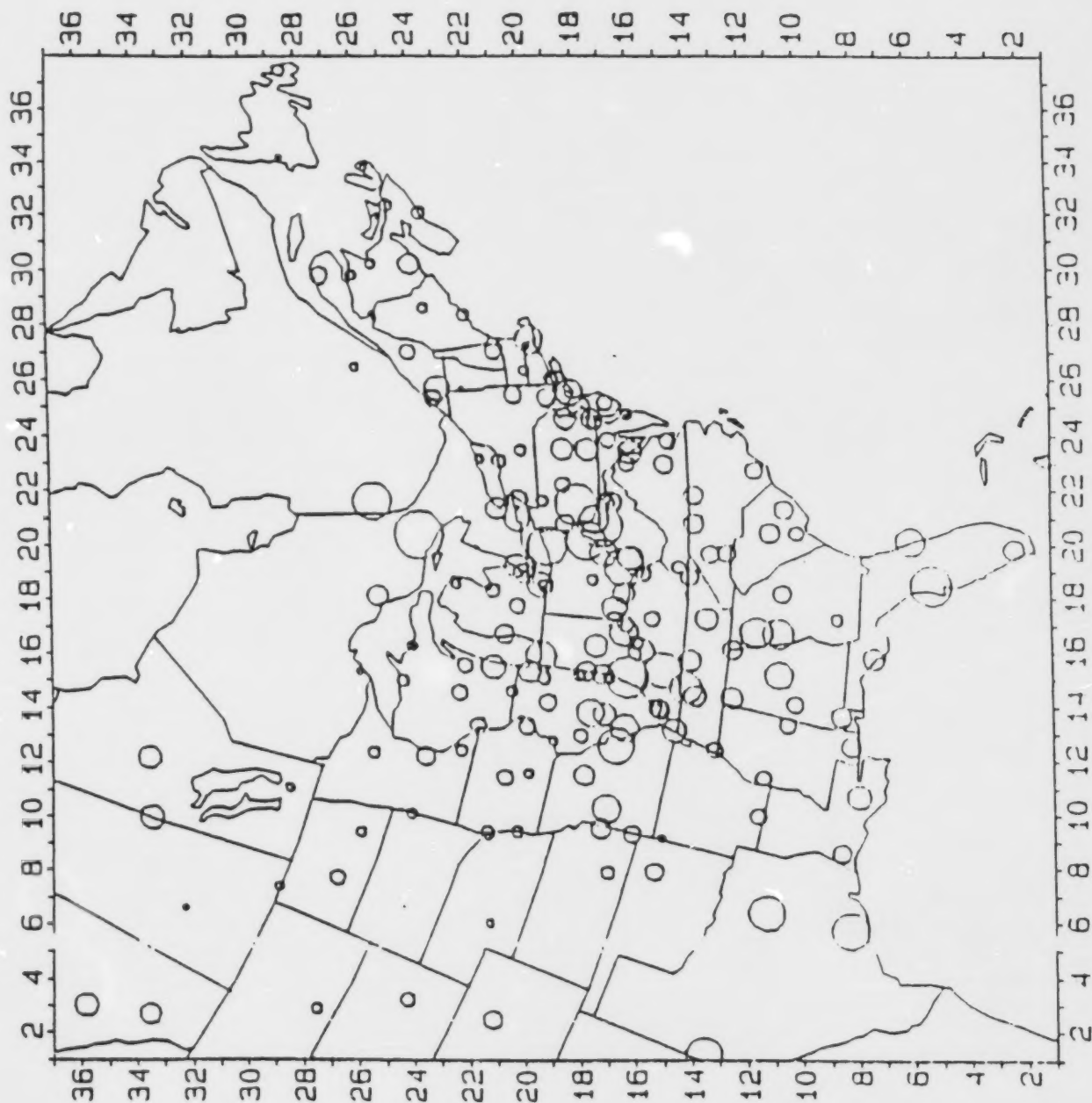


FIGURE 10
THE GRID SYSTEM AND LOCATION OF THE MAJOR SO_2
SOURCES USED WITH THE MOE LAGRANGIAN TRANSPORT MODEL

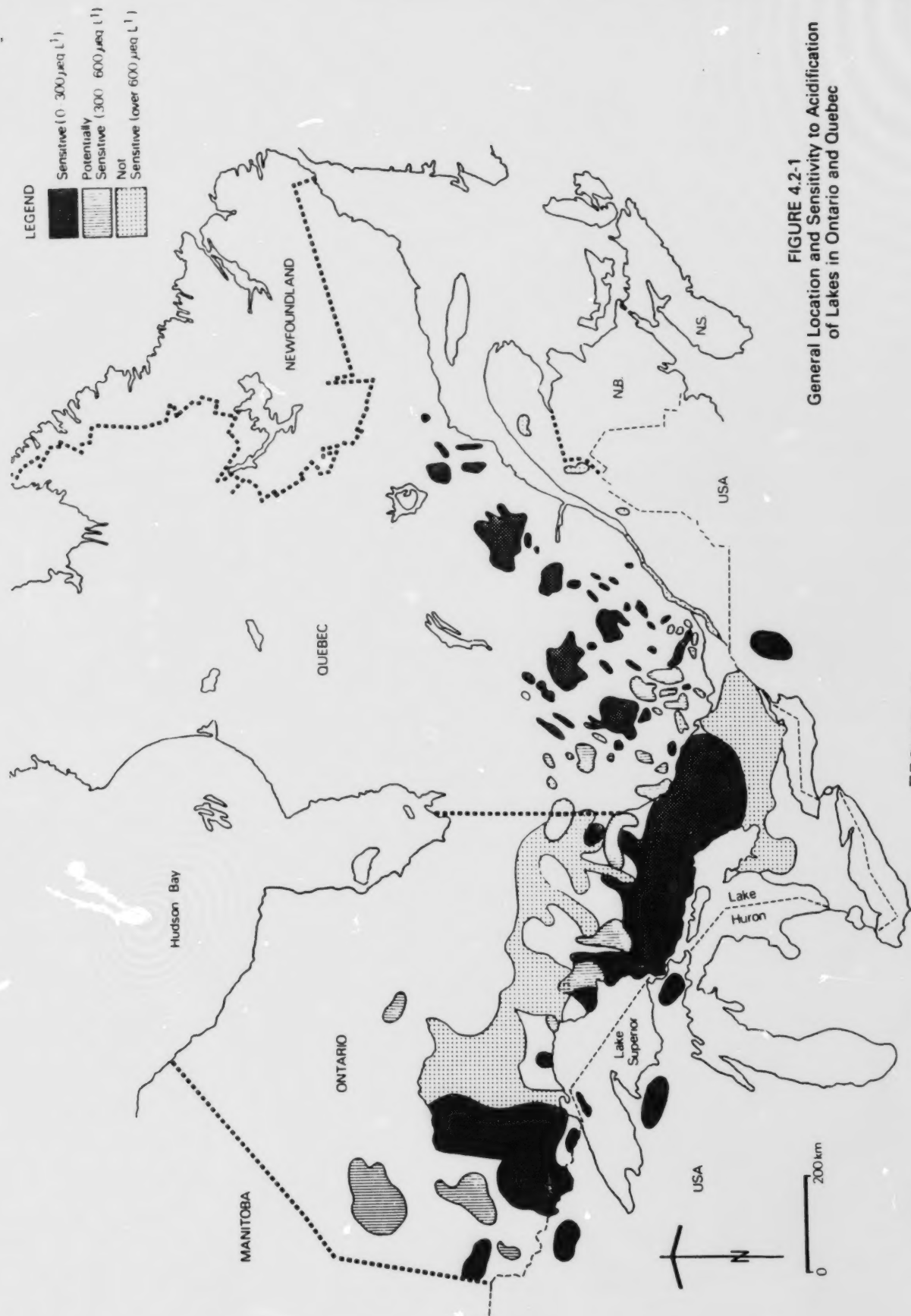


FIGURE 4.2-1
General Location and Sensitivity to Acidification
of Lakes in Ontario and Quebec

FIGURE 11
SENSITIVE RECEPTOR AREAS
(Torrenueva, 1980)

SO₂ CONC. UG/M³

1996-2006

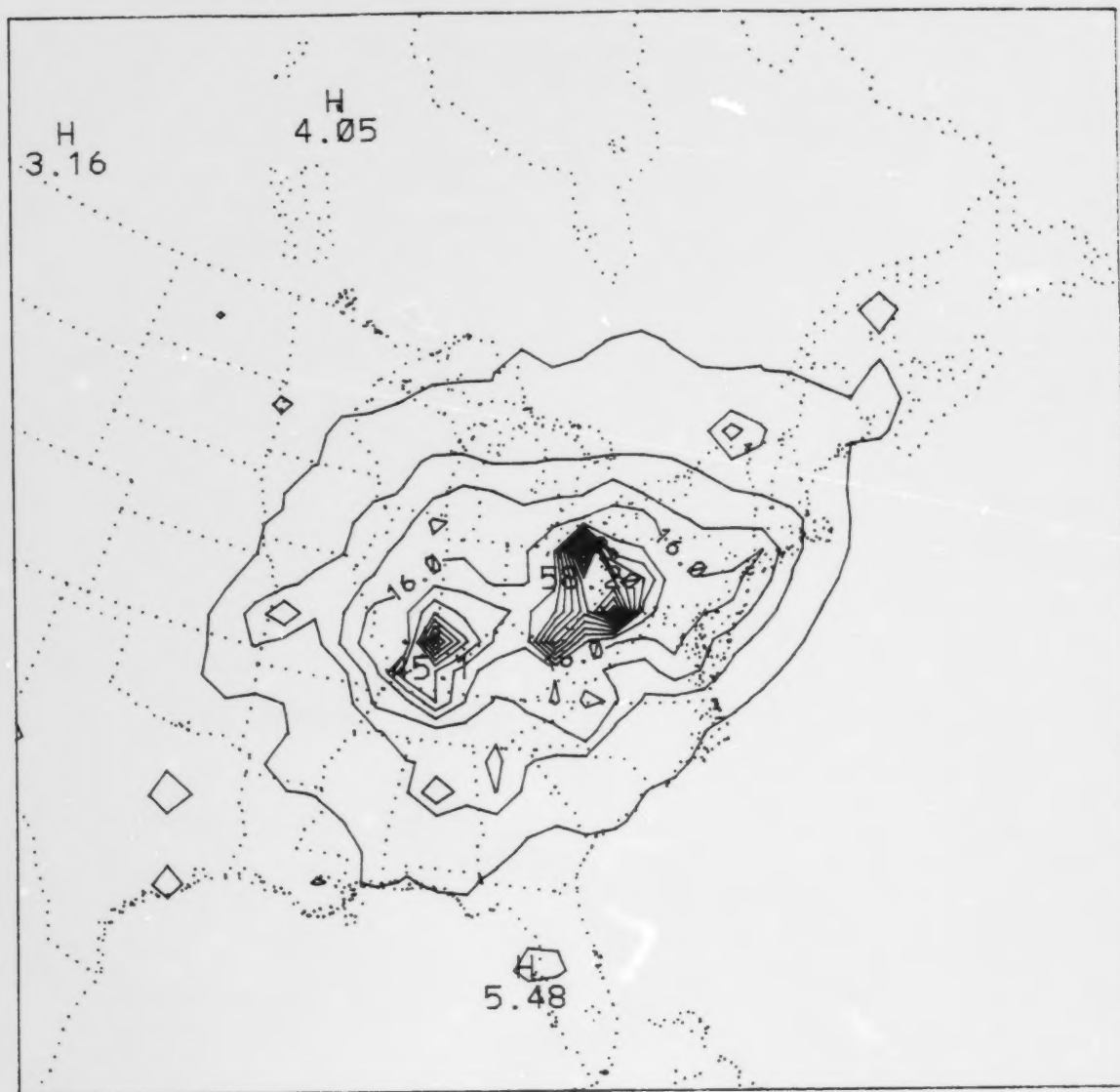


FIGURE 12

DISTRIBUTION OF ANNUAL MEAN SO₂ CONCENTRATION
($\mu\text{g}/\text{m}^3$) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

SO₄

CONC. UG/M3

1996-2006

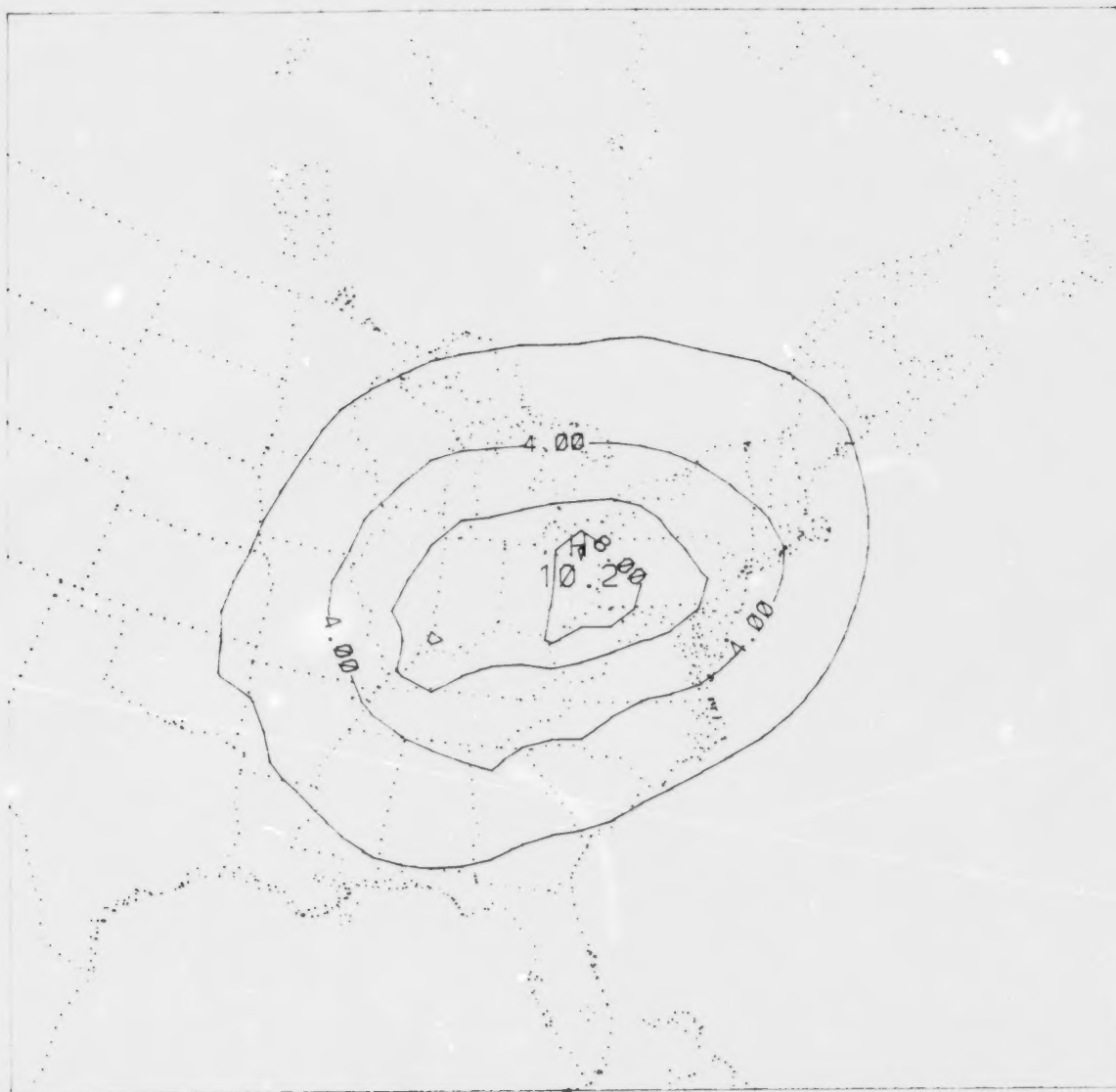


FIGURE 13

DISTRIBUTION OF ANNUAL MEAN SO₄²⁻
CONCENTRATION (µg/m³) FOR THE MEDIUM FOSSIL SCENARIO,
1996-2006

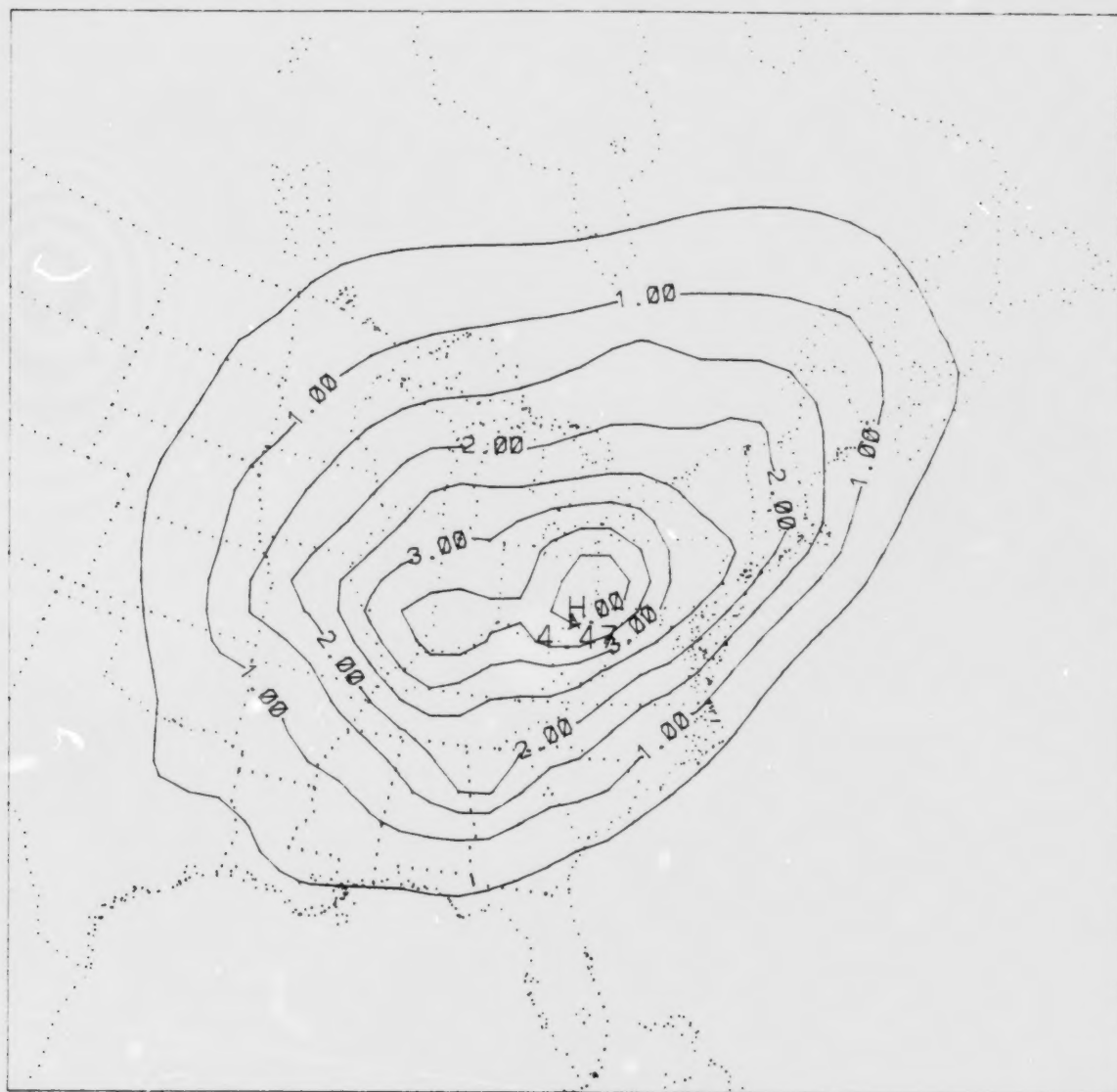


FIGURE 14

DISTRIBUTION OF ANNUAL WET DEPOSITION OF SO_4^{2-} (g/m²)
FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

S DRY DEP. G/M2

1996-2006

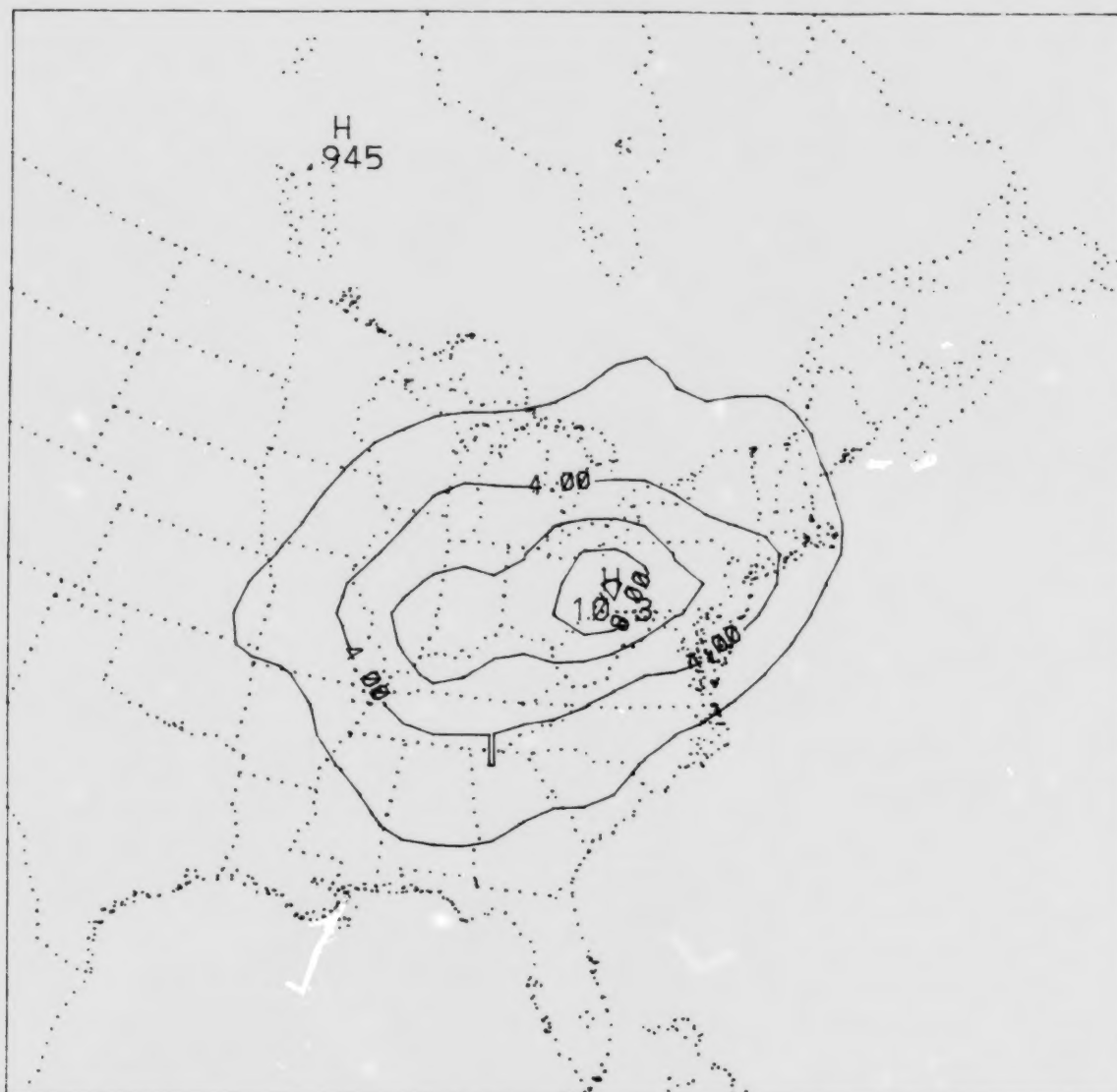


FIGURE 15

DISTRIBUTION OF ANNUAL DRY DEPOSITION OF SO_4^{2-}
(g/m²) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

SO₂ CONC. EXP. PRCTAGE 1996-2006

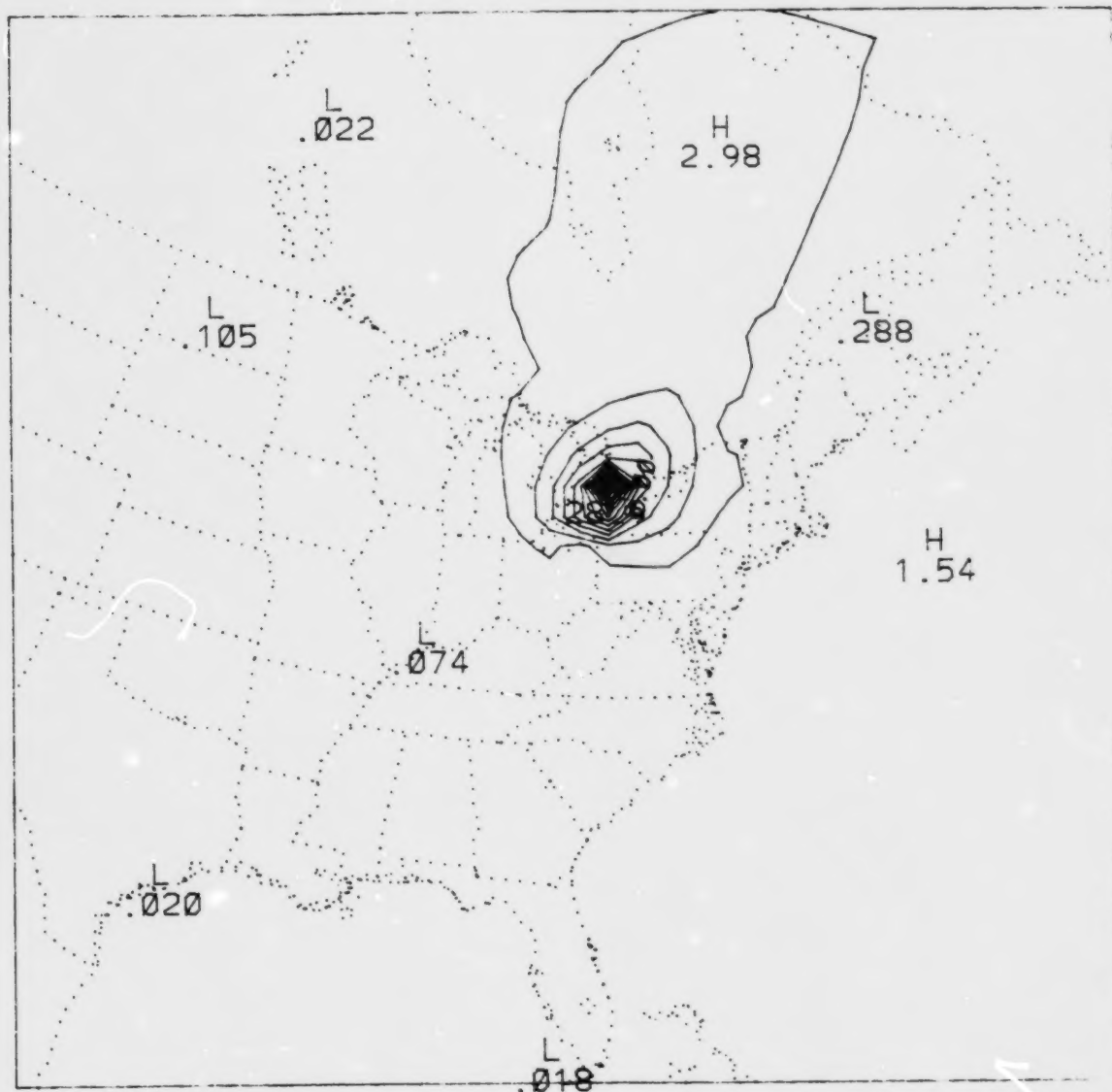


FIGURE 16

DISTRIBUTION OF ANNUAL MEAN SO₂ CONCENTRATION
ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION
(%) OF THE TOTAL SO₂ CONCENTRATION FOR THE
MEDIUM FOSSIL SCENARIO, 1996-2006

SO₄ CONC. EXP. PRCTAGE 1996-2006

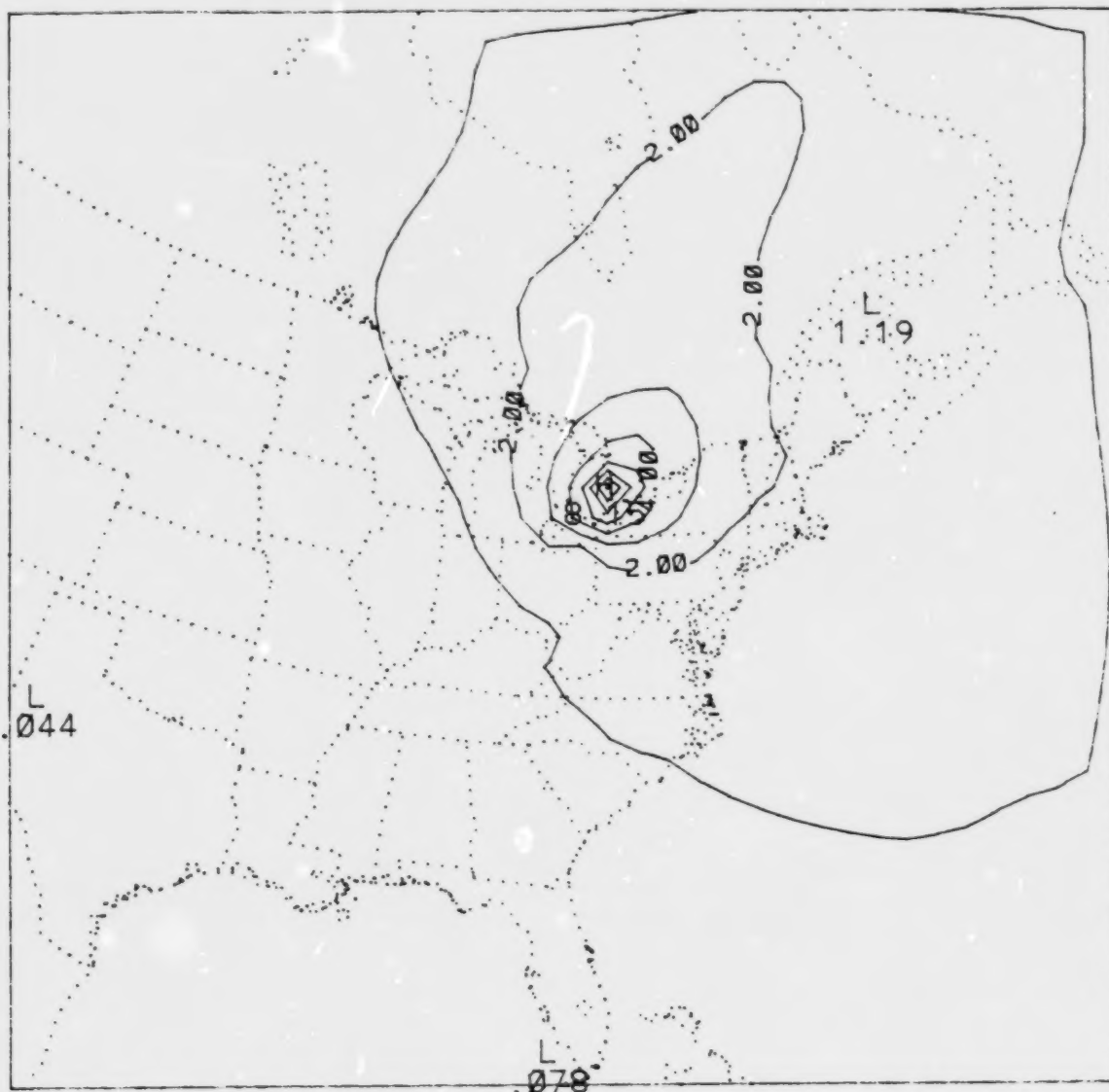


FIGURE 17

DISTRIBUTION OF ANNUAL MEAN SO₄²⁻ CONCENTRATION
ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION
(%) OF THE TOTAL SO₄²⁻ CONCENTRATION FOR THE
MEDIUM FOSSIL SCENARIO, 1996-2006

S WET DEP. EXP. PRCTAGE 1996-2006

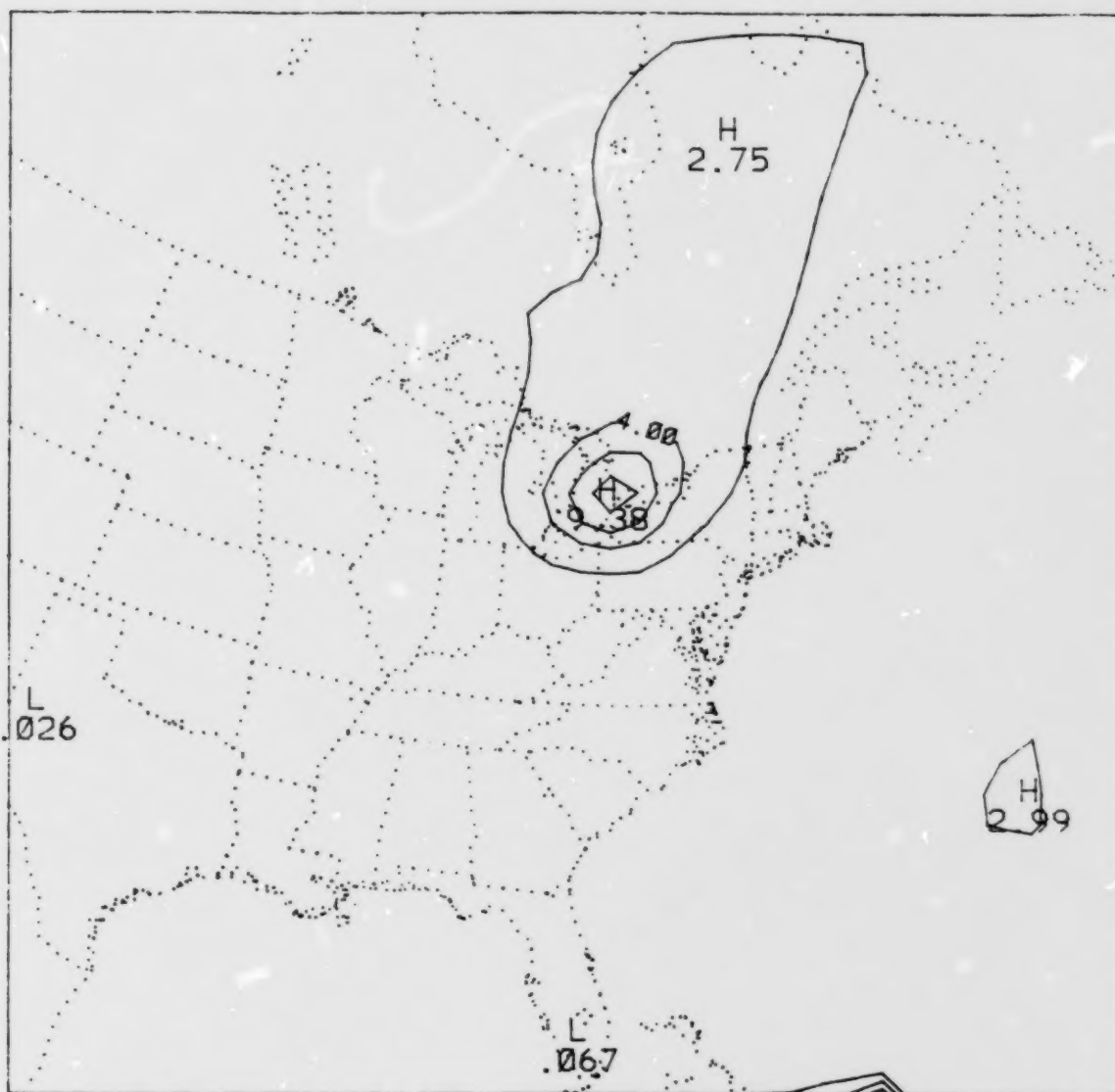


FIGURE 18

DISTRIBUTION OF ANNUAL SO_4^{2-} WET DEPOSITION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL SO_4^{2-} WET DEPOSITION, FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

S DRY DEP. EXP. PRCNTAGE 1996-2006

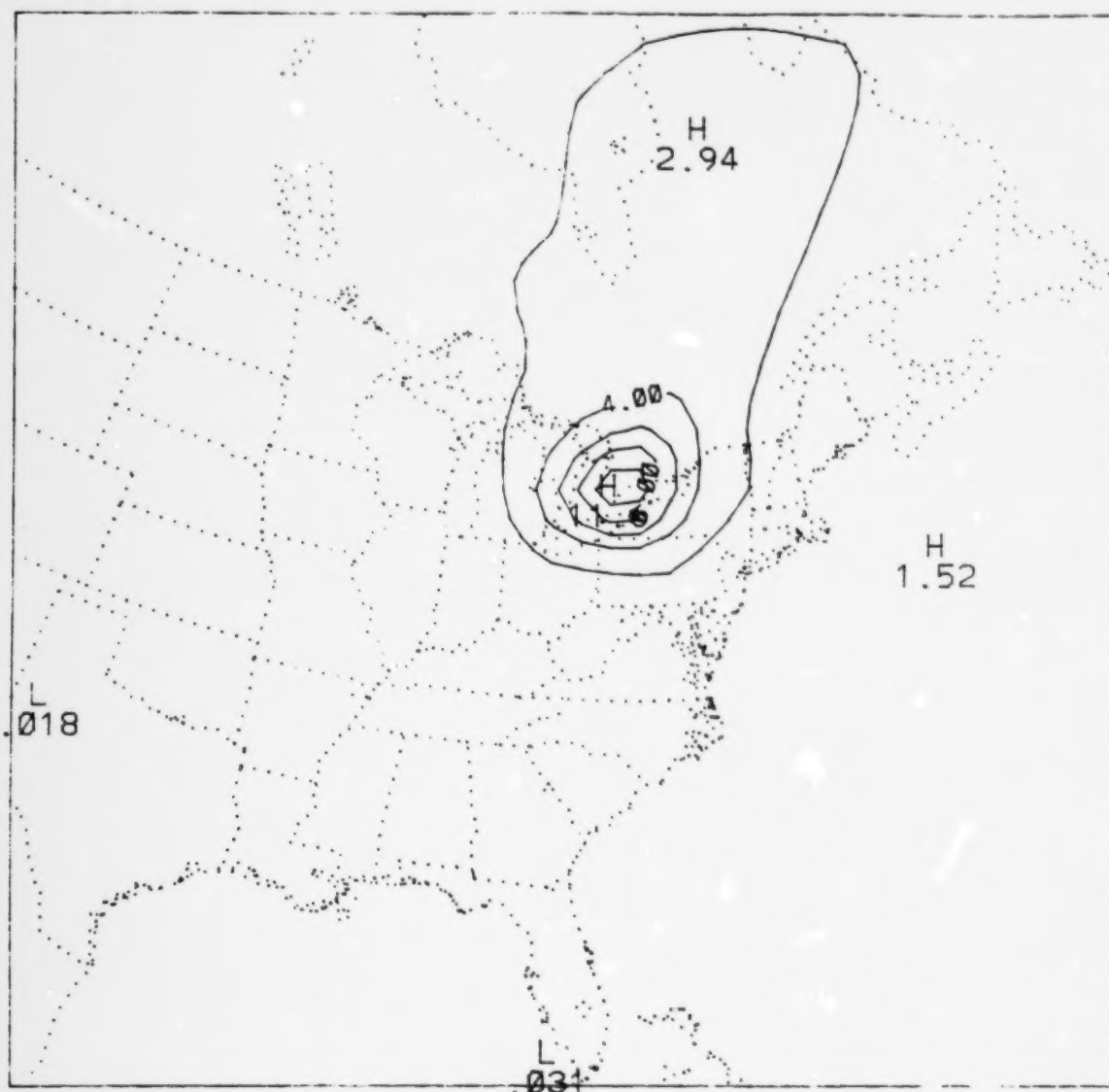


FIGURE 19

DISTRIBUTION OF ANNUAL SO_4^{2-} DRY DEPOSITION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL SO_4^{2-} DRY DEPOSITION, FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

Analysis of the calculated results for the seven acid-sensitive regions indicates the following. For the period 1996-2006 (medium scenario) both the ground-level concentration and the deposition of SO_2 and SO_4^{2-} show larger values in eastern regions than in western regions. The concentrations of SO_2 and SO_4^{2-} are limited within 16 and 5 $\mu\text{g}/\text{m}^3$ respectively. The seasonal variation of SO_2 shows a clear minimum in the summer. In the case of SO_4^{2-} concentration, a semi-annual cycle may be identified with a primary minimum in the winter and a secondary minimum in the summer. On an annual basis, the wet deposition of total sulphur, expressed as sulphate, is comparable to that due to dry deposition. Their annually accumulated values range between 900 mg/m^2 and 3600 mg/m^2 . For the wet deposition, the SO_2 contribution is equivalent to its SO_4^{2-} counterpart because the higher concentration of SO_2 is compensated by its lower scavenging rate, whereas the dry deposition of SO_2 dominates that of SO_4^{2-} simply because of lower concentration and lower dry deposition velocity of SO_4^{2-} .

Considering the fractional contributions due to the total Ontario Hydro emissions, values in the three western sensitive receptor regions (Upper Michigan, Minnesota and Lakehead) are generally lower than in the eastern receptor regions. This reflects the more frequent eastward atmospheric transport in the area; the values are below 10% in the eastern receptor regions and are generally less than 3% in the western receptor regions. It is worth noting that in the western regions lower absolute concentrations and deposition of sulphur, coinciding with the lower percentage, lead to even lower values attributable to Ontario Hydro's stations. Further, contributions of the planned Ontario Hydro export sales to the U.S. account for only about 35% of the contributions due to the total Ontario Hydro emissions at all receptors and for all variables considered here.

6.0 LONG-RANGE TRANSPORT OF NITROGEN -PREDICTIONS FROM ONTARIO HYDRO'S VERSION OF FISHER'S STATISTICAL LONG-RANGE TRANSPORT MODEL

To calculate contributions of Ontario Hydro's export sales to the concentration and deposition of nitrogen species, a version of Fisher's statistical long-range transport model (Wright, 1989) was used. This model, termed "Ontario Hydro's version of Fisher's statistical LRT model" (OHLRT) includes sulphur and nitrogen emissions, transport and deposition. A brief description of OHLRT is presented in Appendix B.

OHLRT was used to calculate annual and seasonal ground-level concentrations, dry and wet deposition of NO_x (NO and NO_2) and NO_3^- . Meteorological input data included the 1980 seasonal values of wind directions, wind speeds, mixing heights, diffusivities and probabilities of occurrence developed by Moran et al, 1985, for the model grid area shown in Figure 20. For the grid area encompassing Lambton TGS, Nanticoke TGS and Lakeview TGS, STAR stability analysis data (wind direction, wind speed, probability of occurrence) by season for the period 1976 to 1985 were used. Seasonal values for the mean lengths of wet and dry periods were taken from Thorp (1986).

Figure 21 illustrates the gridded NO_x emissions which were compiled from 1980 data supplied by the Ontario Ministry of the Environment. The emission scenarios used are described in Section 3.0.



FIGURE 20
OHLRT GRID

Once again model predictions for the entire grid area and the sensitive receptor areas discussed in Section 5.0 were prepared.

Model results (ie, ground-level concentrations and dry and wet deposition), for the medium scenario in the 1996-2006 period are shown in Figures 22-29. Seasonal data and data for other emission scenarios are available in diskette format from the authors. The results show greater values in the eastern sensitive areas (Adirondacks, Haliburton, Muskoka, Algoma) than in the west (Minnesota, Lakehead, Upper Michigan).

Contributions are limited to less than 3%, for the most part less than 1%.

7.0 SHORT-RANGE TRANSPORT

In order to predict the local effects of Ontario Hydro's proposed sales to the U.S. on air quality and dry deposition of various pollutants, a short-range transport model was employed. The model was constructed from the modelling package in Ontario's Clean Air Program Discussion Paper and is capable of giving the air concentrations and dry deposition of pollutants on a local scale. A brief description of the model can be found in Appendix C.

Hourly observed values of wind speed, wind direction, temperature, mixing height, cloud cover and snow cover for 1983 and the three fossil-fuel-fired power stations, ie, Lambton, Nanticoke, and Lakeview were used as input along with the station specification data. Mass distributions of elements in post precipitator ash and in the vapour phase in stack gases, as well as total dust loading (Curtis, 1977) were used to derive annual emissions of 8 elements of interest (Beryllium, Chromium, Nickel, Selenium, Arsenic, Cadmium, Mercury, Lead) for the periods 1991-1993, 1994-1995 and 1996-2006, the latter with low, medium and high fossil-fuel consumption scenarios. The emission data for the 1996-2006 medium scenario are presented in Tables XI. Emissions for other scenarios and time periods may be obtained by scaling the values in Table XI by the ratio of emissions given in Table II. Based on 1983 meteorological data and the projected 1991-1993 annual total emissions, annual mean air concentration of SO_2 , and dry deposition of SO_2 , NO_x (expressed as NO_2), total particulate matter and the 8 trace elements, are presented as isopleths in Figures 30-41. The isopleths are drawn over a square domain of 60 km by 60 km with the power station in the centre. Please refer to Figures 7-9, which have the same grid size, for the geographical details around each power station. In the calculations of dry deposition, we adopted size distribution data from Evans et al. (1984) for the above 8 trace elements while the geometric mean diameter and averaged density of the total particulate matter was assumed to be $3.4 \mu\text{m}$ (Richards et al, 1981) and 2.4 g/cm^3 (T. Chan of Ontario Hydro Research, private communication), respectively. It should be emphasized that the results presented here are values corresponding to the case of Ontario Hydro's total annual emission including sales to the U.S. for the period of 1991-1993. However, because the linearity of ground level concentrations and dry deposition to emission holds, as long as the meteorological conditions, the partitioning and the size distribution of elements are assumed unchanged, we may obtain values for the other cases by simply multiplying the calculated values by the ratio of emissions. For instance, the Lambton SO_2 concentration and dry deposition isopleths (Figures 30 and 31) should be multiplied by

NO₂ CONC. UG/M³ FØR 1996-2006



FIGURE 22

DISTRIBUTION OF ANNUAL MEAN NO₂ CONCENTRATION
(µg/m³) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

NØ3 CØNC. UG/M3 FØR 1996-2006



FIGURE 23

DISTRIBUTION OF ANNUAL MEAN NO_3^- CONCENTRATION
($\mu\text{g}/\text{m}^3$) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

N WET DEPOSITION G/M2 FØR 1996-2006

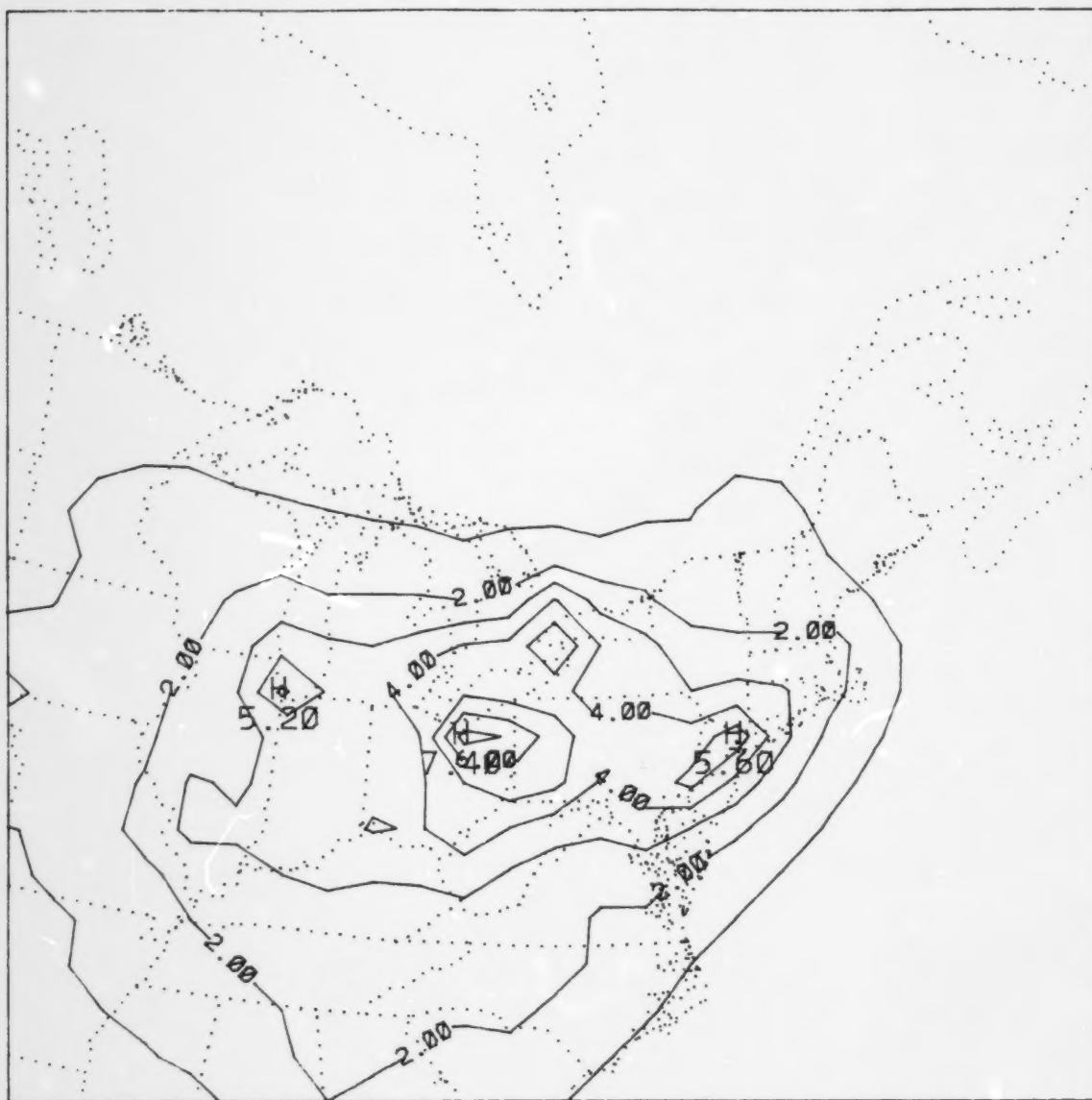


FIGURE 24

DISTRIBUTION OF ANNUAL WET DEPOSITION OF NO_3^-
(g/m²) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

N DRY DEPOSITION G/M2 FOR 1996-2006

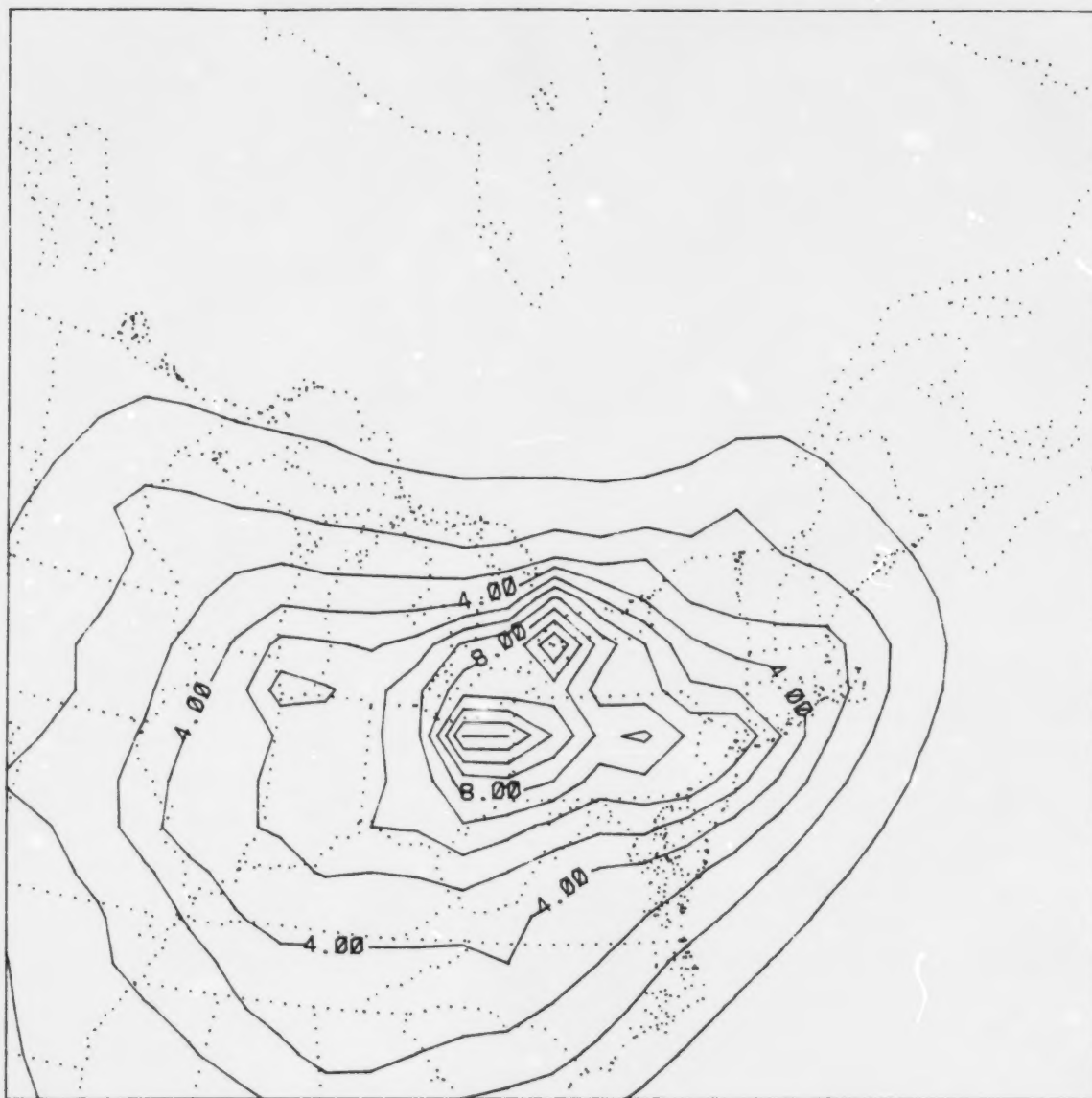


FIGURE 25

DISTRIBUTION OF ANNUAL DRY DEPOSITION OF NO_3^-
(g/m²) FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

NO₂ CONC. EXP. PRCNTAGE 1996-2006

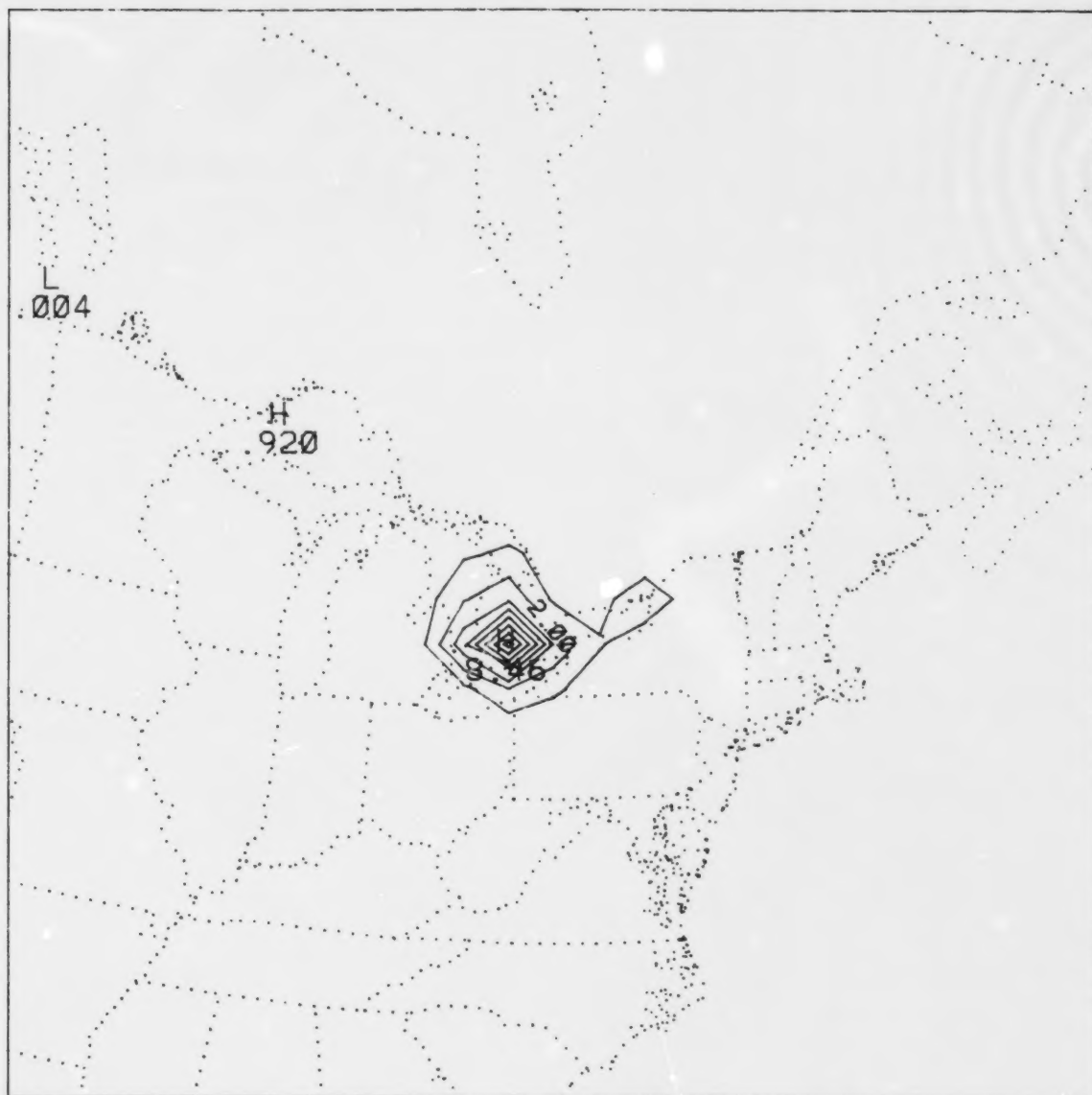


FIGURE 26

DISTRIBUTION OF ANNUAL MEAN NO₂ CONCENTRATION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL NO₂ CONCENTRATION FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

NO₃ CONC. EXP. PRCNTAGE 1996-2006

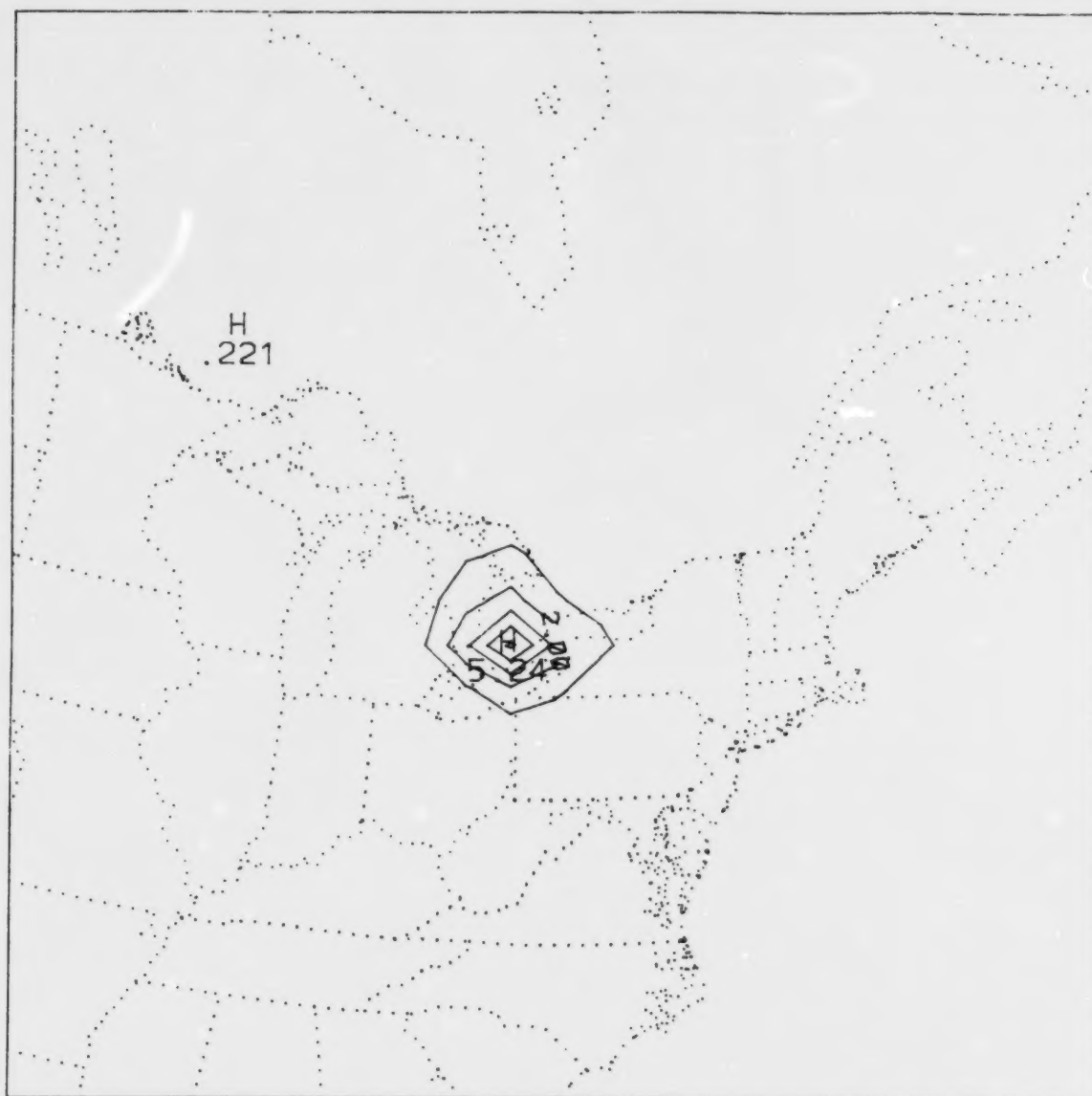


FIGURE 27

DISTRIBUTION OF ANNUAL MEAN NO₃⁻ CONCENTRATION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL NO₃⁻ CONCENTRATION FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

N WET DEPOSITION EXP. PRCNTAGE 1996-2006

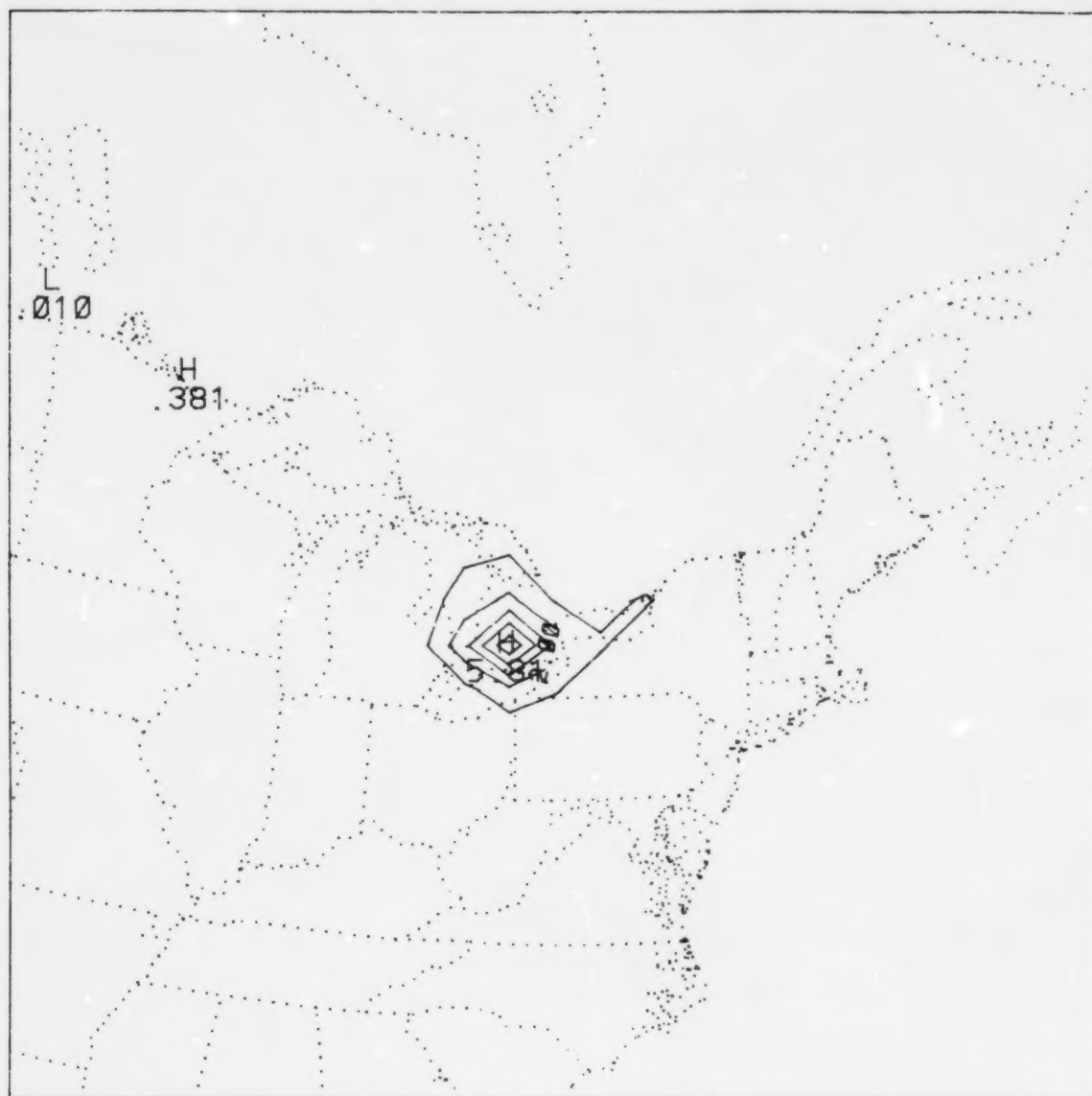


FIGURE 28

DISTRIBUTION OF ANNUAL NO_3^- WET DEPOSITION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL NO_3^- WET DEPOSITION, FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

N DRY DEPOSITION EXP. PRCNTAGE 1996-2006

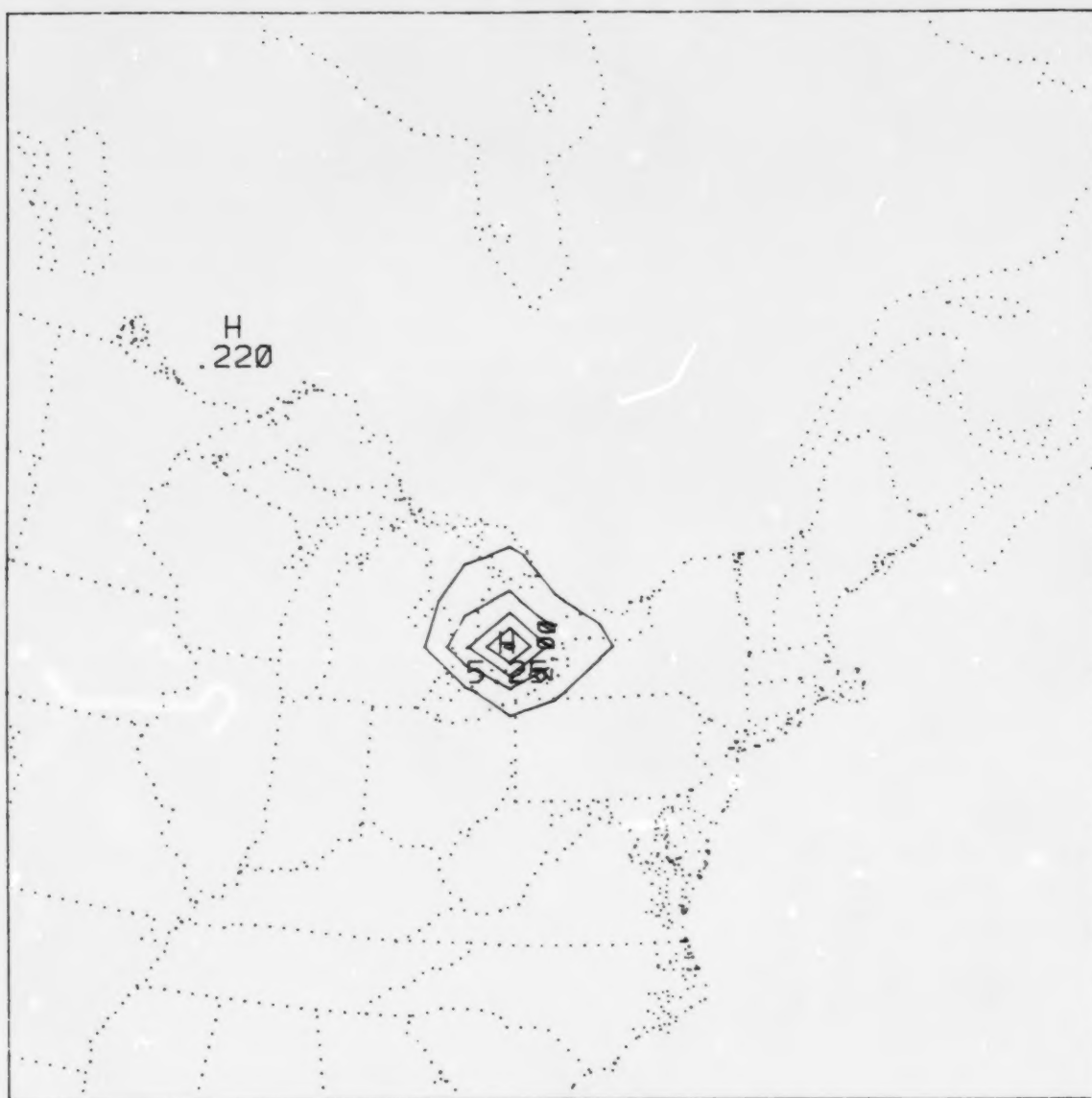
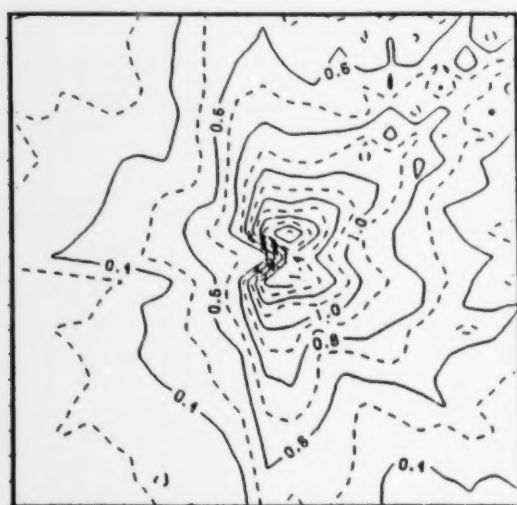


FIGURE 29

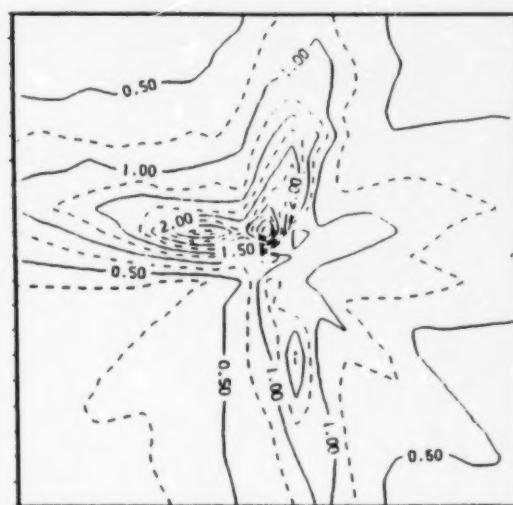
DISTRIBUTION OF ANNUAL NO_3^- DRY DEPOSITION ATTRIBUTABLE TO EXPORTS, EXPRESSED AS A FRACTION (%) OF THE TOTAL NO_3^- DRY DEPOSITION, FOR THE MEDIUM FOSSIL SCENARIO, 1996-2006

TABLE XI
PROJECTED EMISSION DATA (Mg)
1996-2006 MEDIUM FOSSIL-FUEL SCENARIO

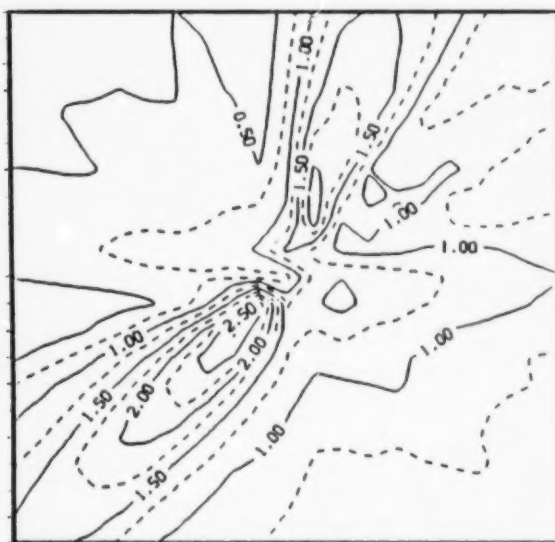
	Lambton		Nanticoke		Lakeview	
	<u>Total</u>	<u>Exports</u>	<u>Total</u>	<u>Exports</u>	<u>Total</u>	<u>Exports</u>
SO ₂	2.36x10 ⁴	5.20x10 ³	4.21x10 ⁴	1.75x10 ⁴	1.78x10 ⁴	1.06x10 ⁴
NO	1.28x10 ⁴	2.80x10 ³	1.80x10 ⁴	7.50x10 ³	4.50x10 ³	2.70x10 ³
Particulate Matter	2.75x10 ³	6.10x10 ²	2.51x10 ³	1.04x10 ³	5.30x10 ²	3.10x10 ²
Beryllium	7.70x10 ⁻³	1.71x10 ⁻³	3.92x10 ⁻³	1.62x10 ⁻³	7.57x10 ⁻⁴	4.43x10 ⁻⁴
Chromium	2.43x10 ⁻¹	5.39x10 ⁻²	1.67x10 ⁻¹	6.91x10 ⁻²	3.39x10 ⁻²	1.99x10 ⁻²
Nickel	2.20x10 ⁻¹	4.88x10 ⁻²	1.52x10 ⁻¹	6.31x10 ⁻²	3.10x10 ⁻²	1.82x10 ⁻²
Selenium	2.11x10 ⁻¹	4.68x10 ⁻²	1.13x10 ⁻¹	4.69x10 ⁻²	2.21x10 ⁻²	1.29x10 ⁻²
Arsenic	2.05x10 ⁻¹	4.55x10 ⁻²	1.19x10 ⁻¹	4.92x10 ⁻²	2.35x10 ⁻²	1.37x10 ⁻²
Cadmium	8.19x10 ⁻³	1.82x10 ⁻³	7.04x10 ⁻³	2.92x10 ⁻³	1.48x10 ⁻³	8.63x10 ⁻⁴
Mercury	2.20x10 ⁻¹	4.88x10 ⁻²	2.35x10 ⁻¹	9.75x10 ⁻²	5.05x10 ⁻²	2.95x10 ⁻²
Lead	1.42x10 ⁻¹	3.15x10 ⁻²	8.38x10 ⁻²	3.47x10 ⁻²	1.67x10 ⁻²	9.74x10 ⁻³



LANTON TGS



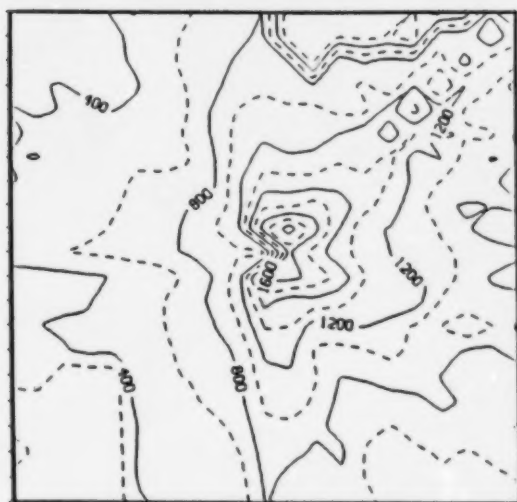
LAKEVIEW TGS



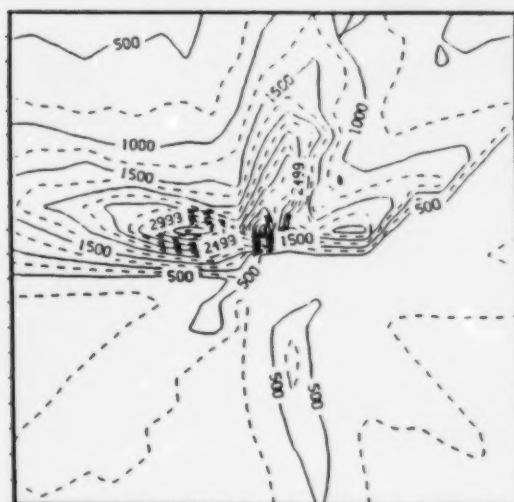
NANTICOKE TGS

Figure 30

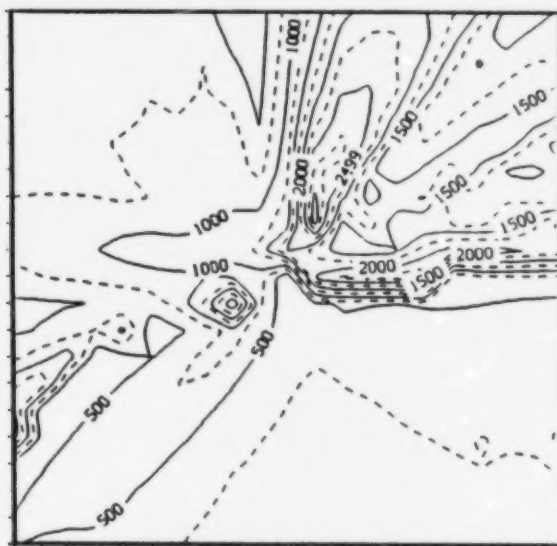
PREDICTED ANNUAL AIR CONCENTRATION FOR 1991-1993
SPECIE: SO_2 in $\mu\text{g}/\text{m}^3$



LEXINGTON TGS



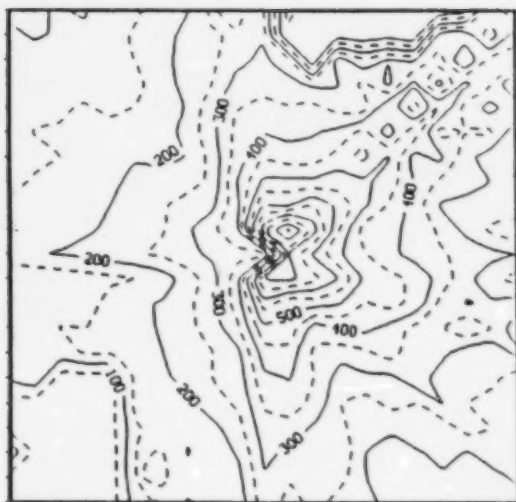
LAKEVIEW TGS



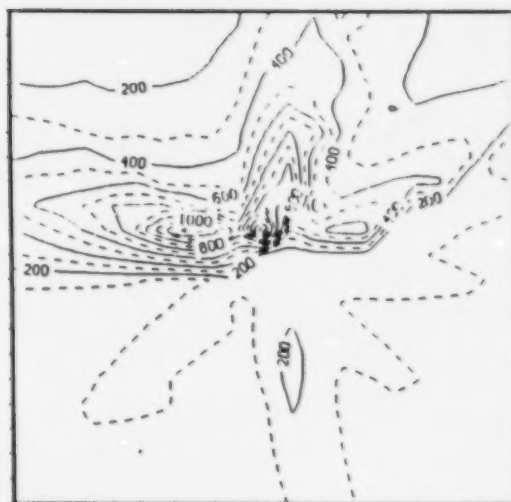
NANTICOKE TGS

Figure 31

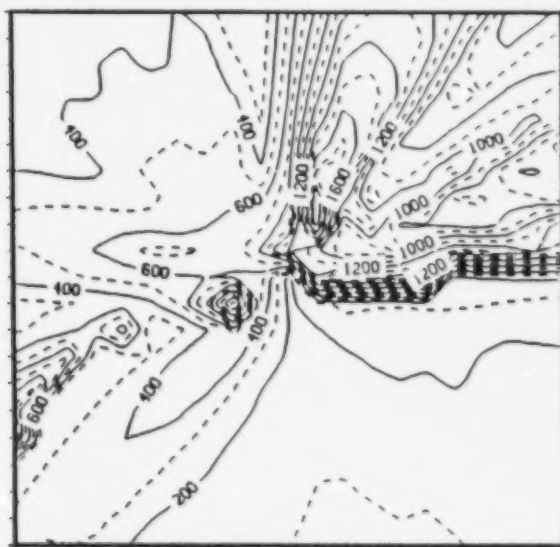
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
SPECIE: SO₂ in mg/m³



LAMONT TGS



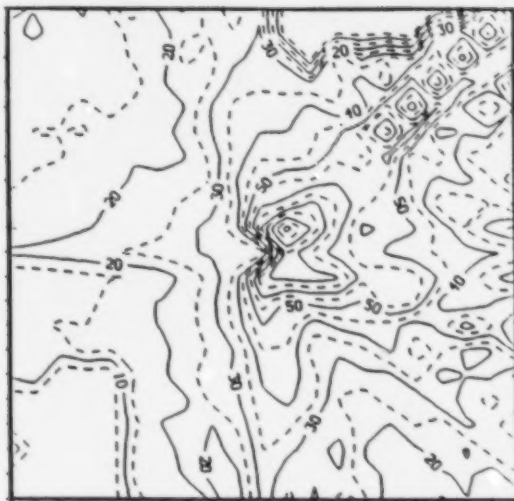
LAKEVIEW TGS



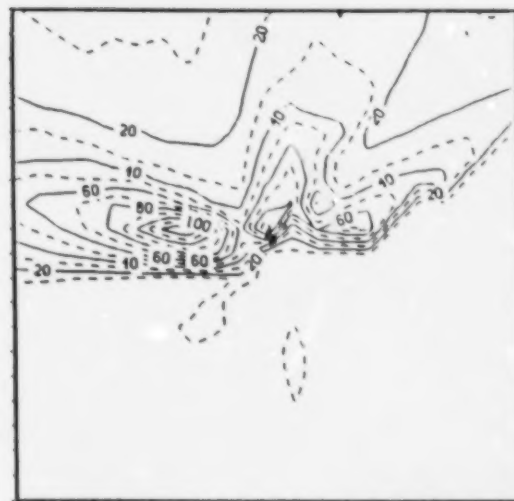
NANTICONE TGS

Figure 32

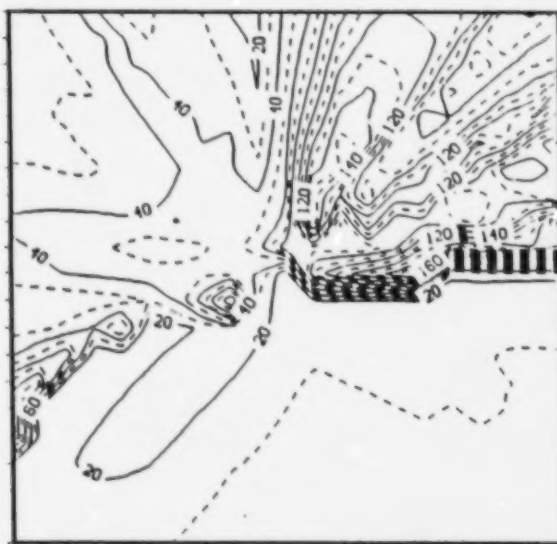
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
SPECIE: NO_x in mg/m



LEBSTON TGS



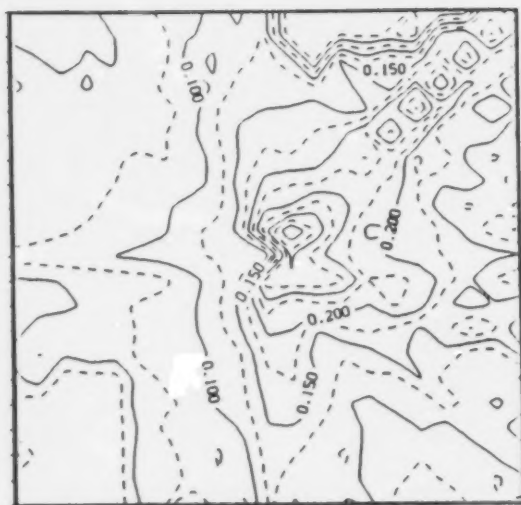
LAKEVIEW TGS



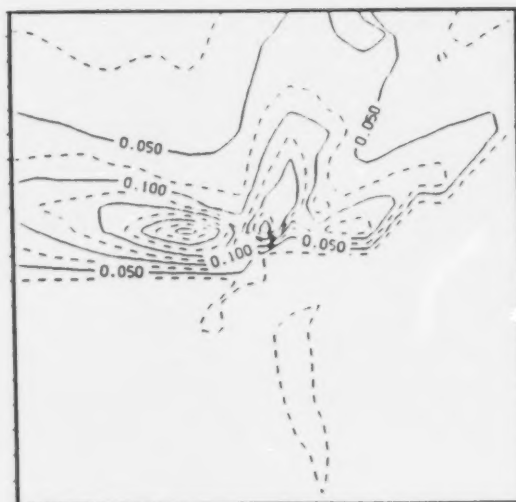
NANTICOKE TGS

Figure 33

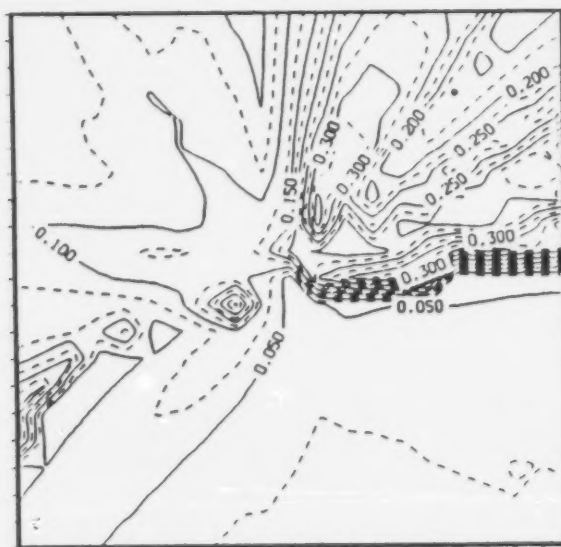
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
Total Particulates in mg/m



LAMSTON TGS



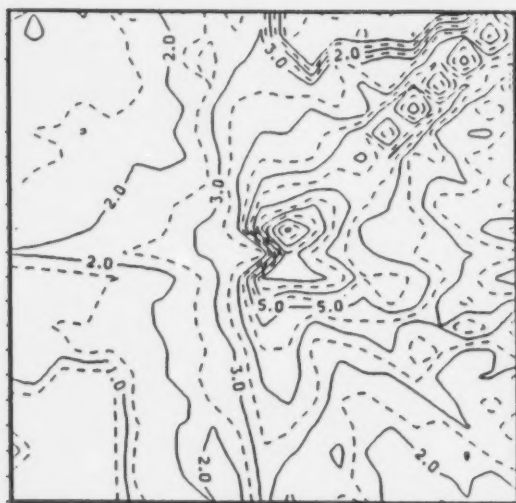
LAKEVIEW TGS



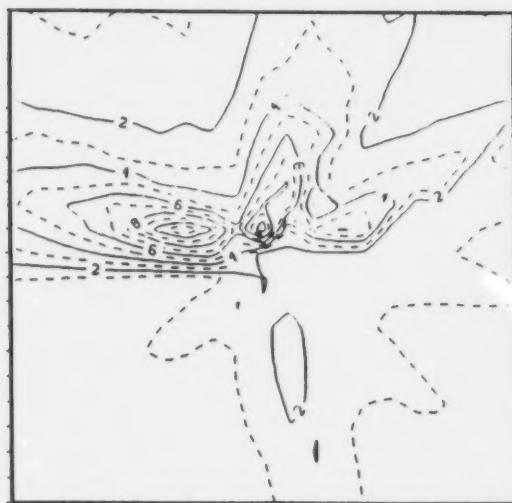
NANTICOKE TGS

Figure 34

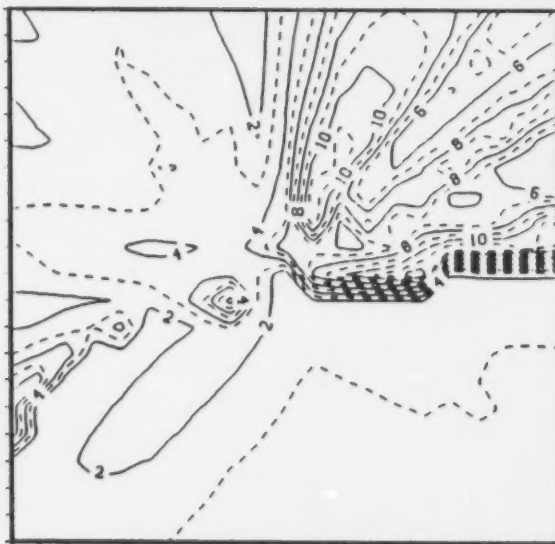
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Be in $\mu\text{g}/\text{m}^2$



LAMONT TGS



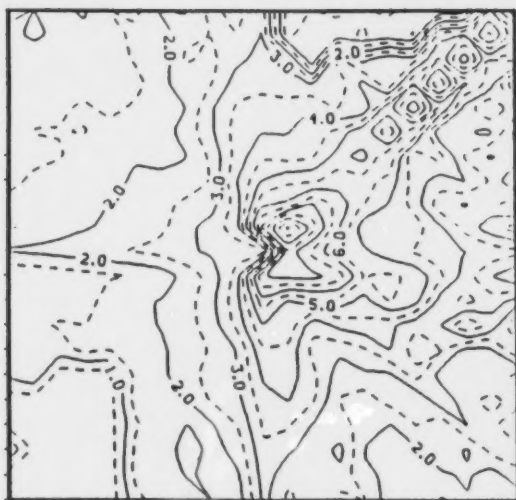
LAKEVIEW TGS



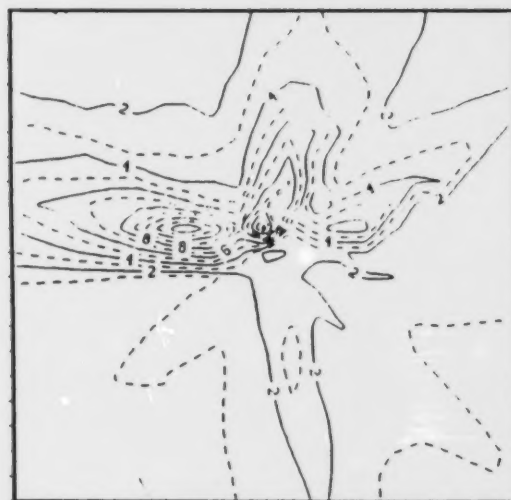
NANTICOKE TGS

Figure 35

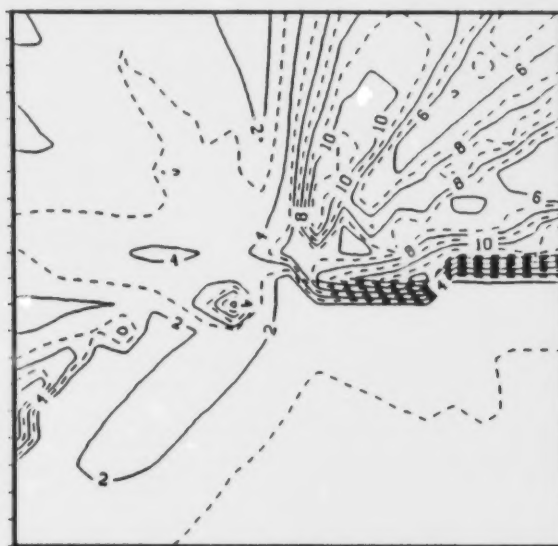
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Cr in $\mu\text{g}/\text{m}^3$



LAMINGTON TGS



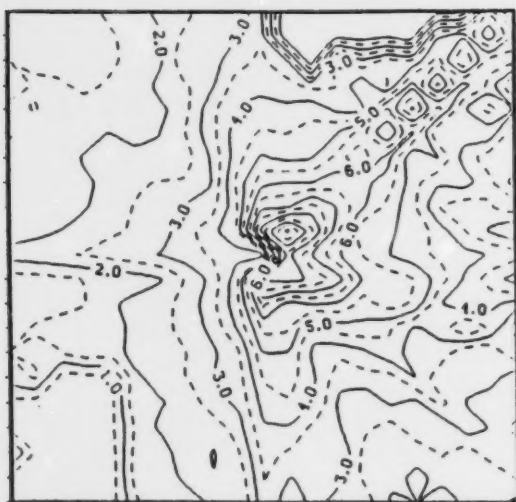
LAKEVIEW TGS



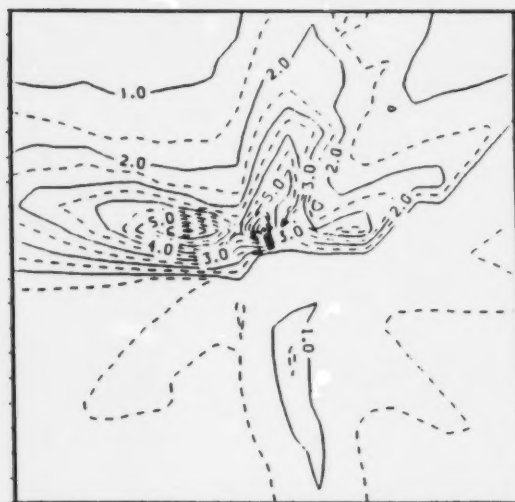
NANTICOKE TGS

Figure 36

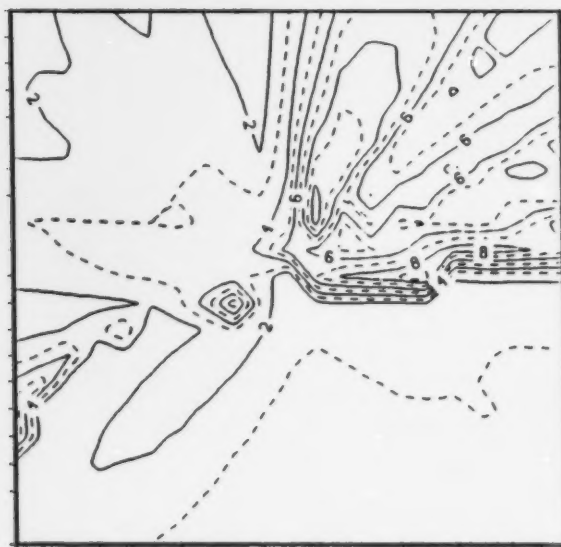
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ELEMENT: Ni in ug/m³



LAWTON TGS



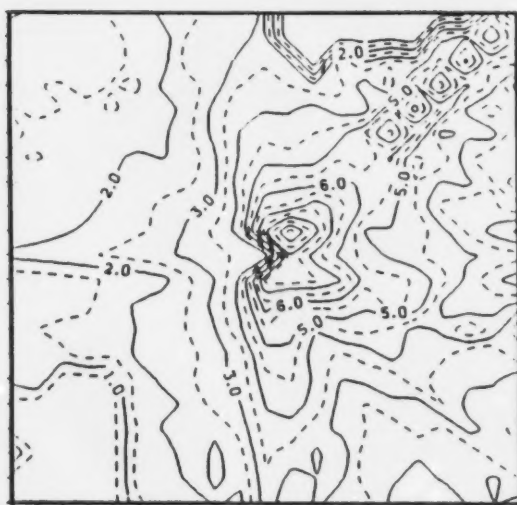
LAKEVIEW TGS



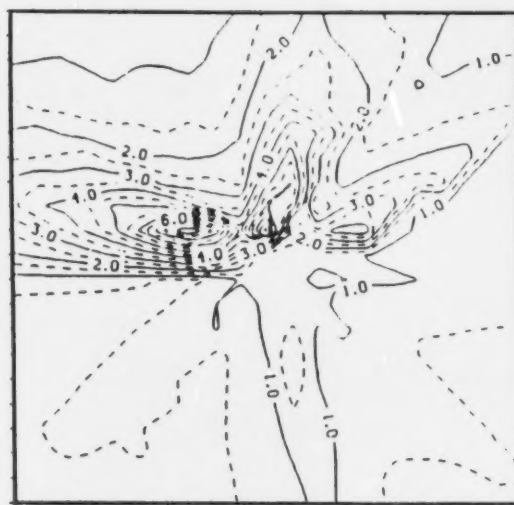
NANTICOKE TGS

Figure 37

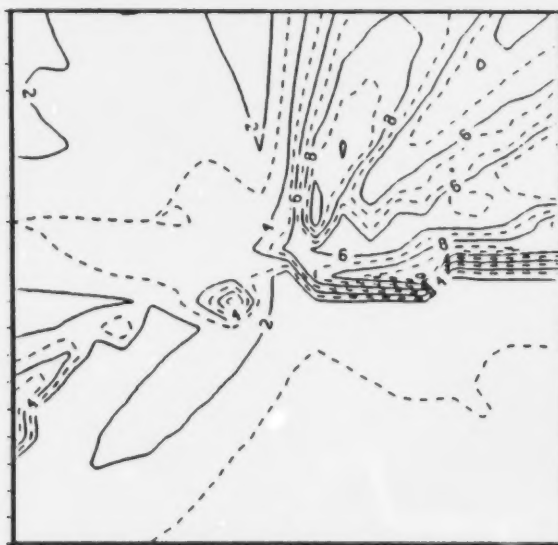
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Se in $\mu\text{g}/\text{m}^2$



LARINGTON TGS



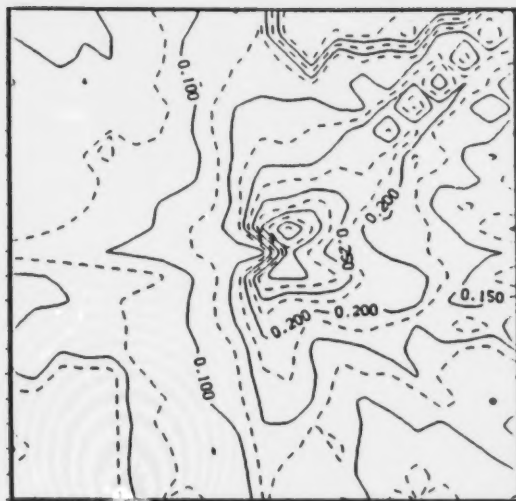
LAKEVIEW TGS



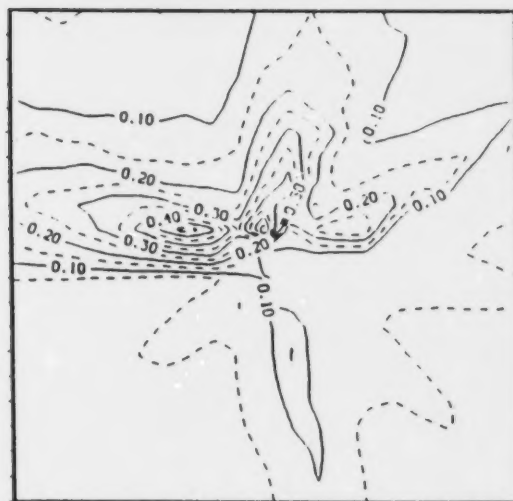
NANTICOKE TGS

Figure 3a

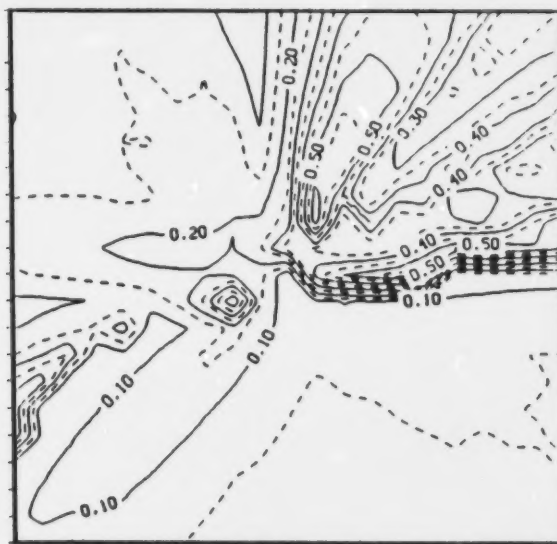
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: As in ug/m³



LABISTON TGS



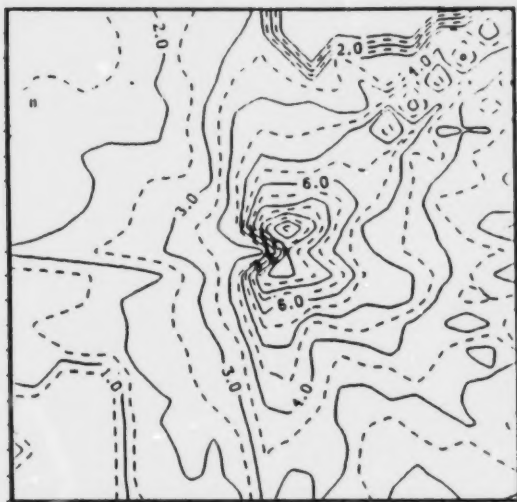
LAKEVIEW TGS



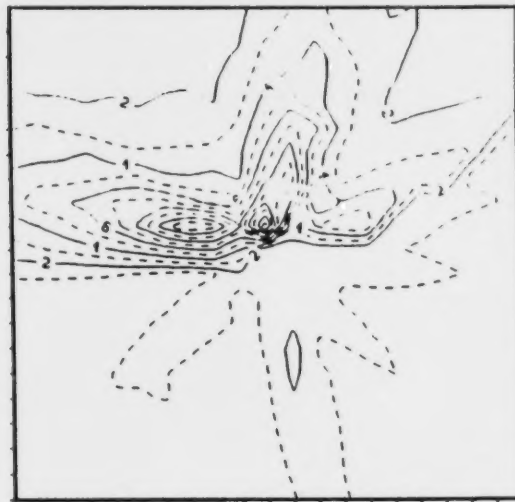
NANTICOKE TGS

Figure 39

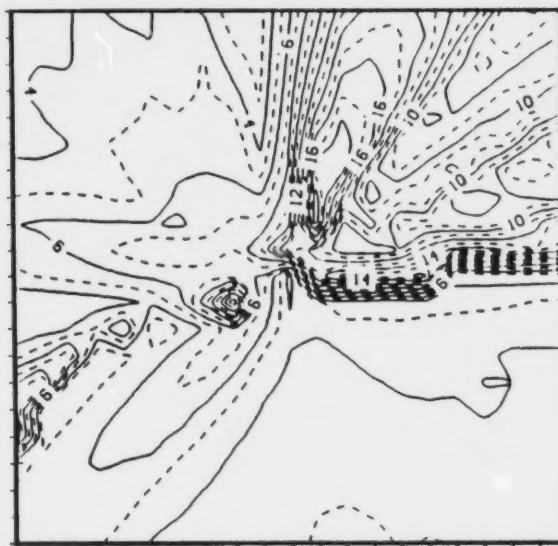
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Cd in $\mu\text{g}/\text{m}^3$



LABSTON TGS



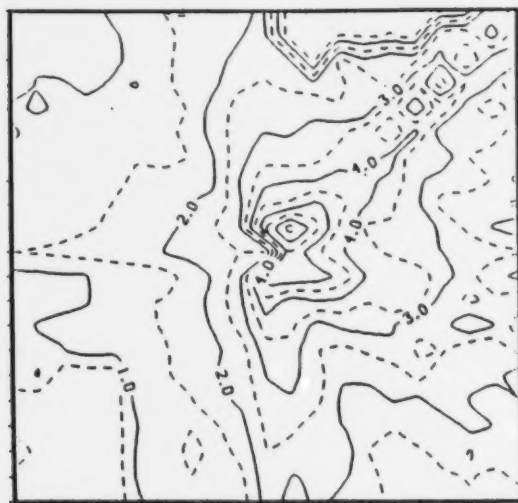
LAKEVIEW TGS



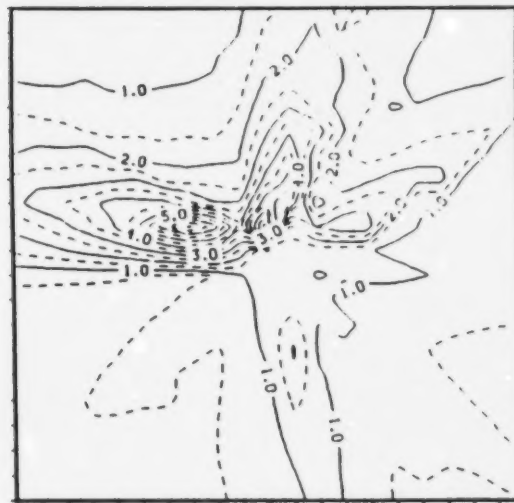
NANTICOKE TGS

Figure 40:

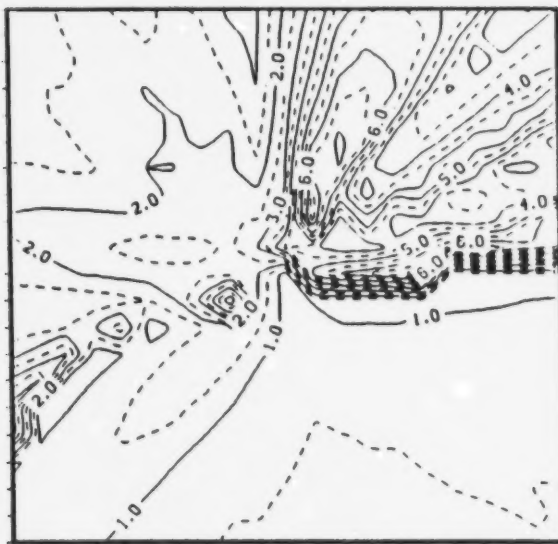
PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Hg in ug/m³



LAMOTON TGS



LAKEVIEW TGS



HANTICORE TGS

Figure 41

PREDICTED ANNUAL DRY DEPOSITION FOR 1991-1993
ELEMENT: Pb in ug/m³

$1.85 \times 10^4 / 3.48 \times 10^4 = 0.53$ to obtain the fraction due to exports in the period 1991-1993 and $1.22 \times 10^4 / 3.48 \times 10^4 = 0.35$ for the period 1994-1995.

Seasonal data and data for the other scenarios and time periods are available in diskette format from the authors.

8.0 CONCLUDING REMARKS

The contribution of Ontario Hydro's proposed electricity exports, during 1991-2006, to air pollutant concentrations and deposition in Ontario and vicinity has been estimated in this study. This was done through the use of pollutant transport and deposition models, suitable for both short-range and long-range transport. In order to apply these models, representative meteorological data were selected (1983 for short-range transport calculations and 1982 or 1976-1985 for long-range transport calculations). As well, emissions data, representing conditions in 1980-82 were adopted as a baseline which was then modified to take into account the implementation of acid rain control legislation in Eastern Canada, and Ontario Hydro's projections of export sales.

The long-range transport calculations indicate that Ontario Hydro's contribution to ambient concentrations and deposition of sulphur and nitrogen species at sensitive receptor areas is below 5% and that at most 30% of this contribution is due to the proposed electricity exports. On a local scale, the contributions of the three larger power stations (Lambton, Nanticoke and Lakeview) to air pollutant concentrations is somewhat higher, particularly at Nanticoke where the background air quality is better and the power plant is the major local source of, say, SO_2 and NO_x . Results are presented in both annual and seasonal averages in order to facilitate the calculation of seasonally-dependent impacts.

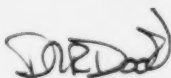
In order to estimate social costs it will be necessary to establish where on the dose-response curves the contributions due to exports should be examined. This requires establishing the total air pollutant concentration and deposition. The same transport and deposition models were used to obtain the contributions due to all sources. In addition, air quality and precipitation chemistry monitoring data collected in recent years were summarized for this purpose.

It is possible that some of the data required for the social costs study may not be included in the report. In that case, it is suggested that requests for additional data be communicated to the author of this report.

ACKNOWLEDGEMENT

P.K. Misra and R. Bloxam of the Ontario Ministry of the Environment helped with the Lagrangian model calculations, while A. Tang provided environmental monitoring data. R. Vet of AES provided additional monitoring data. A number of individuals in other Ontario Hydro Divisions provided data - A. Douglas, R. Gorski, J. Walewski. M. Fleming did a masterful job of producing the report.

Approved by:



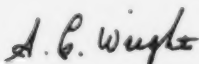
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Chemical Research Department

Prepared by:

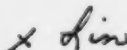


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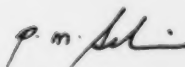
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APPENDIX A

THE ONTARIO MINISTRY OF THE ENVIRONMENT'S LAGRANGIAN TRAJECTORY MODEL

The Lagrangian trajectory model of long-range transport simulates continuous emissions from point sources as discrete puffs travelling along trajectories of the tropospheric wind field that is changing with time and space. The model includes a linear transformation of sulphur dioxide to particulate sulphate along the trajectory as well as their deposition on the surface. The model is applied on a grid array of 38 x 37 points with a grid size of 127 km. The domain covers a region of eastern North America, centred on the great lakes, east of the Rockies as shown in Figure 11. Trajectories initiated from 182 sources are calculated every three hours during the first 12 hours after plume release and at six-hour intervals thereafter for a four-day period. All the trajectories initiated from each source during the specified averaging period, ie, a year or a month, are considered as a statistical ensemble. However, when averaging over a month, the size of the ensemble is not large enough for statistical purposes. Therefore, a Gaussian distribution of mass over the horizontal area of an expanding puff is imposed. To do that, a standard deviation is set to $r/2$ where r is the radius of the puff that is proportional to the square root of the product of a horizontal diffusivity and the elapsed time. Along each of the trajectories, concentrations of gaseous SO_2 and particulate SO_4^{2-} are calculated by the following mass conservation equations:

$$\frac{dq}{dt} = - (K_d + K_w + K_i) q$$

$$\frac{ds}{dt} = - (\overline{K_d} + \overline{K_w}) s + \frac{3}{2} K_i q$$

where q and s denote concentrations of SO_2 and SO_4^{2-} , respectively. In the equations, K_d and K_w represent removal rates at the surface for dry and wet conditions, respectively, with the overbars relating to SO_4^{2-} . K_i is the conversion rate of SO_2 to SO_4^{2-} and the coefficient "3/2" reflects the relative ratio of their molecular weight. Values of the above parameters were discussed in detail by Ellenton et al. (1985).

To assess the performance of the model, the model was run with meteorological and SO_2 emission data for the years 1978, 1979, 1980 and 1982. The calculated monthly wet deposition of sulphate was then compared against monitoring data available from 8 sites for the period of 1978 -1980 and 1982 while the modelled annual wet deposition of sulphate for 1980 was compared with measurements made at 54 sites. These monitoring sites are part of the Canadian Air and Precipitation Monitoring Network (APN), the Canadian Network for Sampling Precipitation (CANSAP), the Ontario Ministry of the Environment's APIOS Network, the Multistate Atmospheric Power Production Pollution Study (MAP3S),

the US National Atmospheric Deposition Program (NADP) and the Utility Acid Precipitation Study Program (UAPSP). The comparison between predictions and observations is presented in Figures A.1 through A.10. The simulated monthly wet deposition at the eight monitoring sites shows seasonal patterns that are in reasonable agreement with measurements. The correlation coefficient between modelled and measured monthly wet deposition of sulphate is 0.69 while the one based on annual data is 0.71. That means that the model explains 47% and 50% of the variance in the measured monthly and annual wet deposition of sulphate, respectively, for the periods mentioned above.

In addition to the above comparison, an International Sulphur Deposition Model Evaluation (ISDME) project was carried out to evaluate eleven linear-chemistry atmospheric models of sulphur deposition by using performance measures based on the ability of the models to replicate the spatial patterns of observed seasonal variables. According to model performance scores, the Lagrangian model of the Ontario Ministry of the Environment was rated as one of the two top models compared (Clark et al, 1987).

Figure A.1

Comparison between predicted and observed
wet sulphate deposition at Simcoe, Ontario

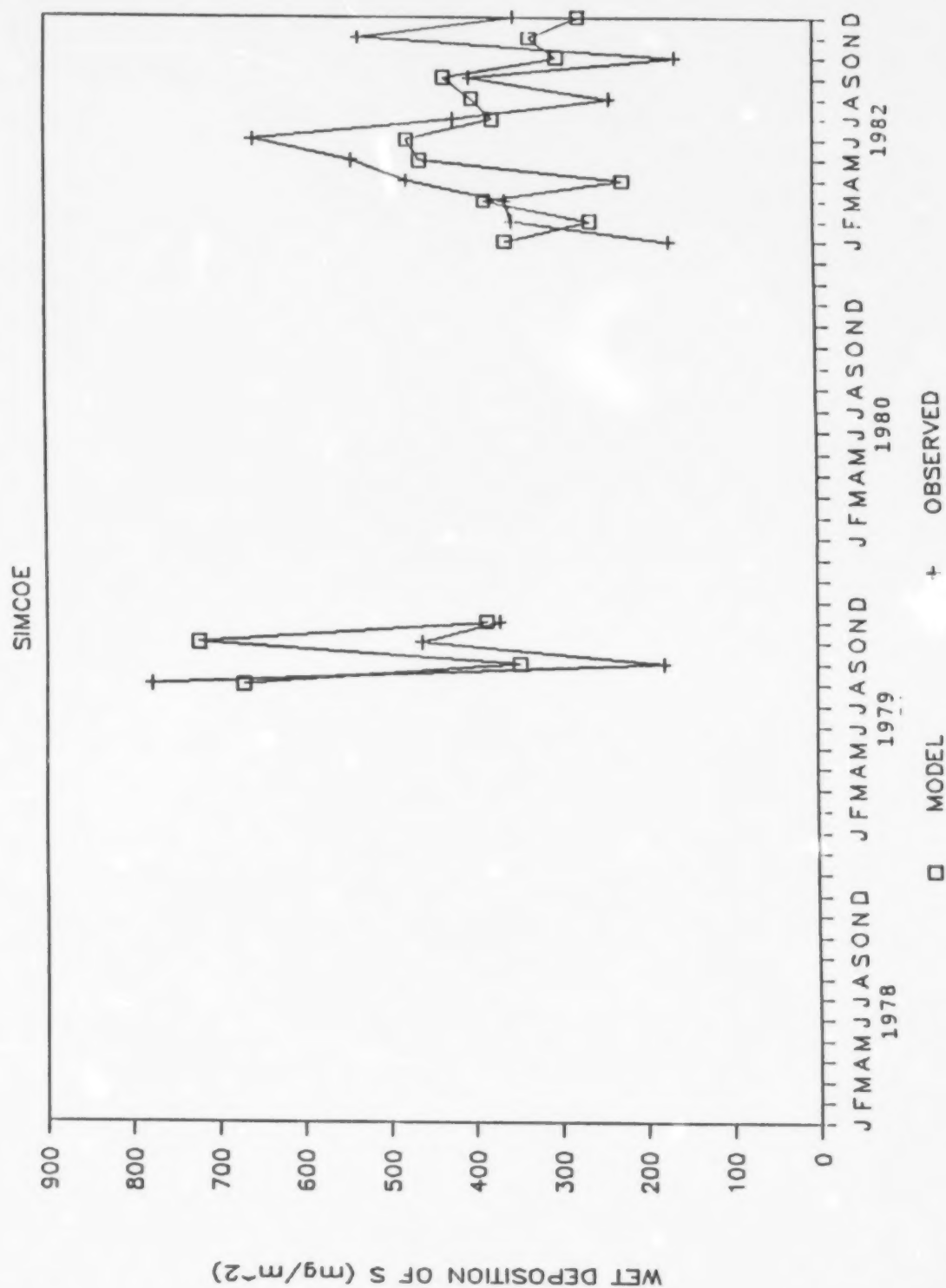


Figure A.2

Comparison between predicted and
observed wet sulphate deposition at Long Point,
Ontario

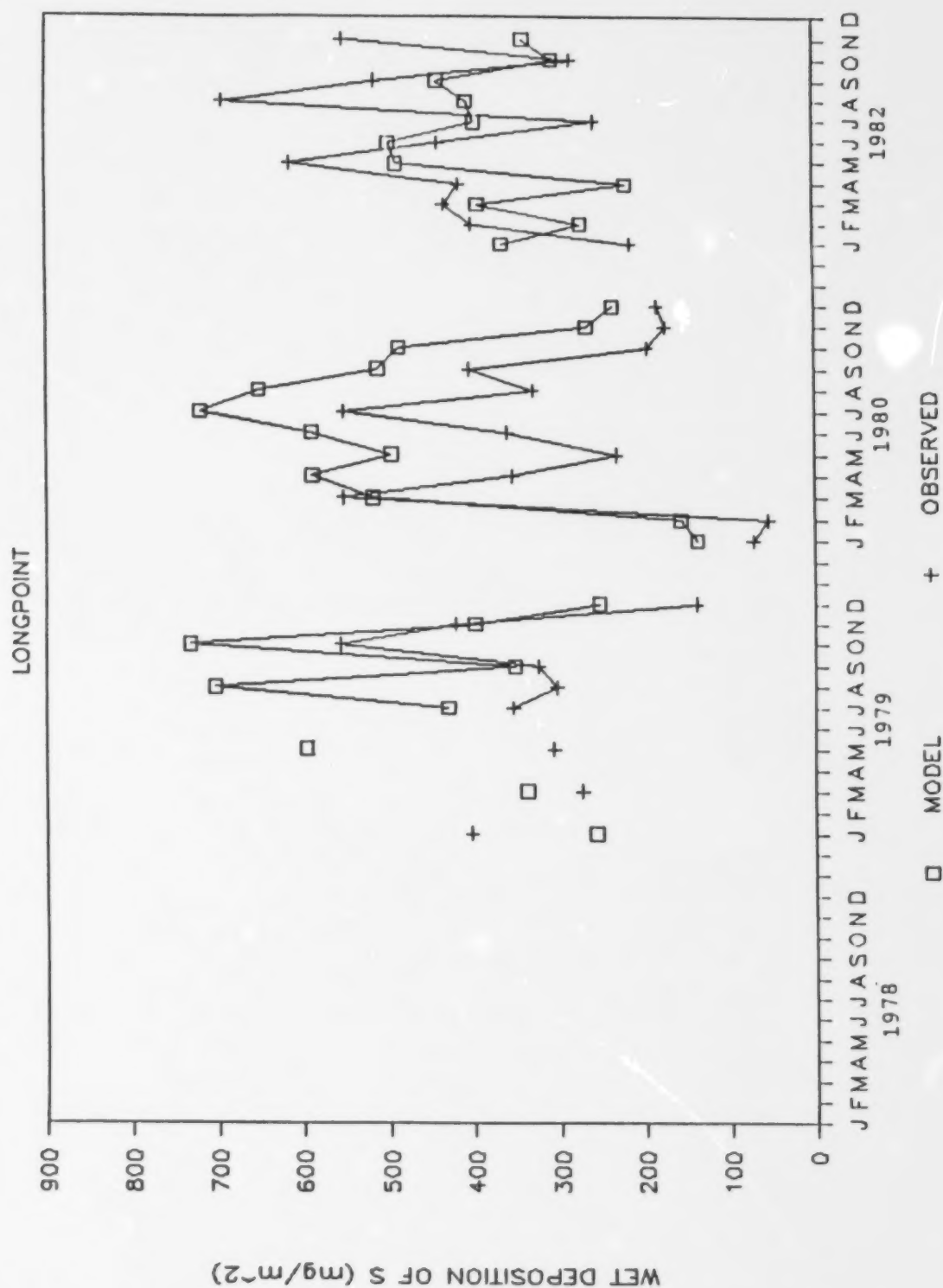


Figure A.3

Comparison between predicted and observed wet sulphate deposition at the Experimental Lakes Area, Ontario

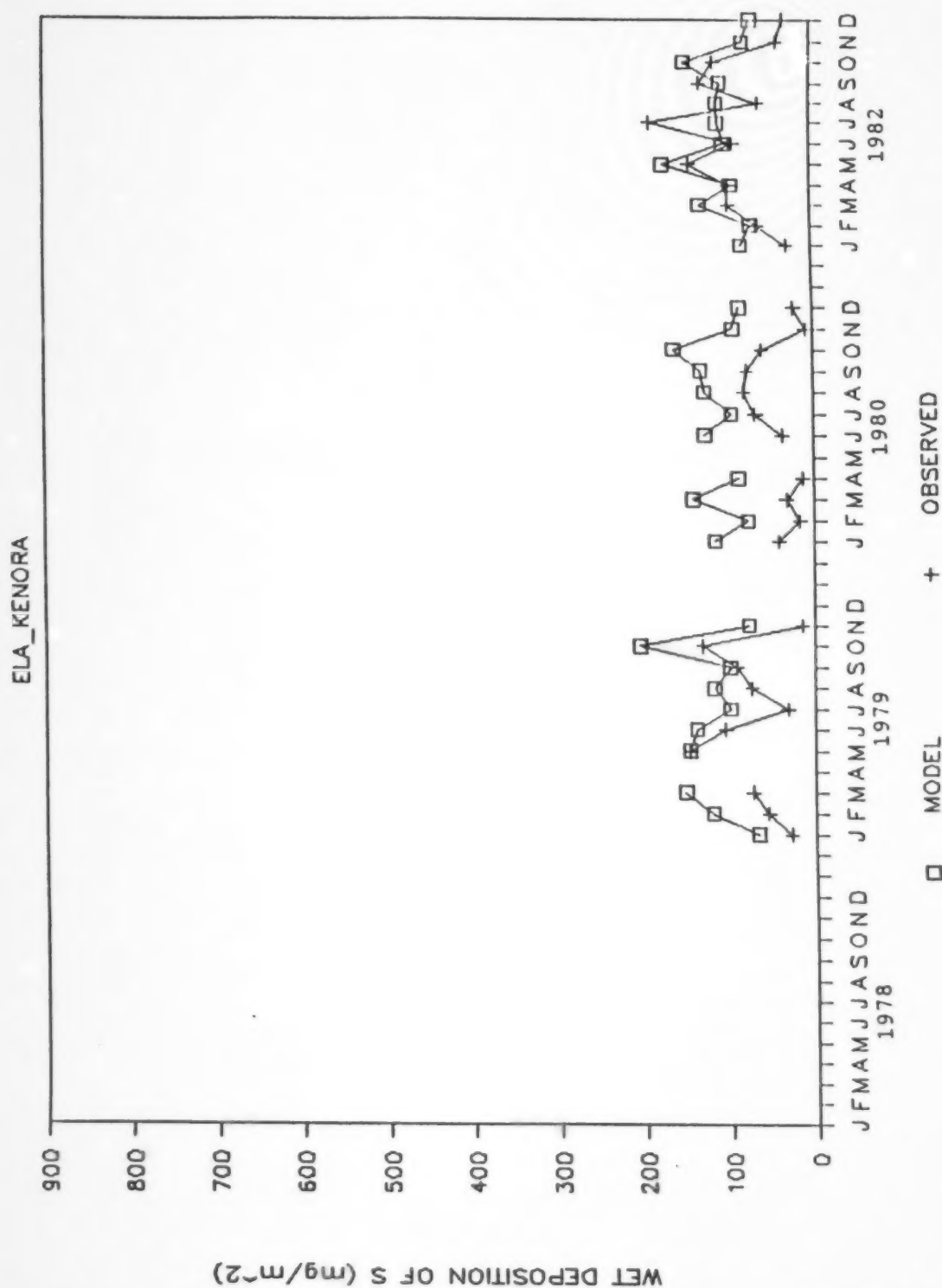


Figure A.4

Comparison between predicted and observed wet sulphate deposition at Dorset, Ontario

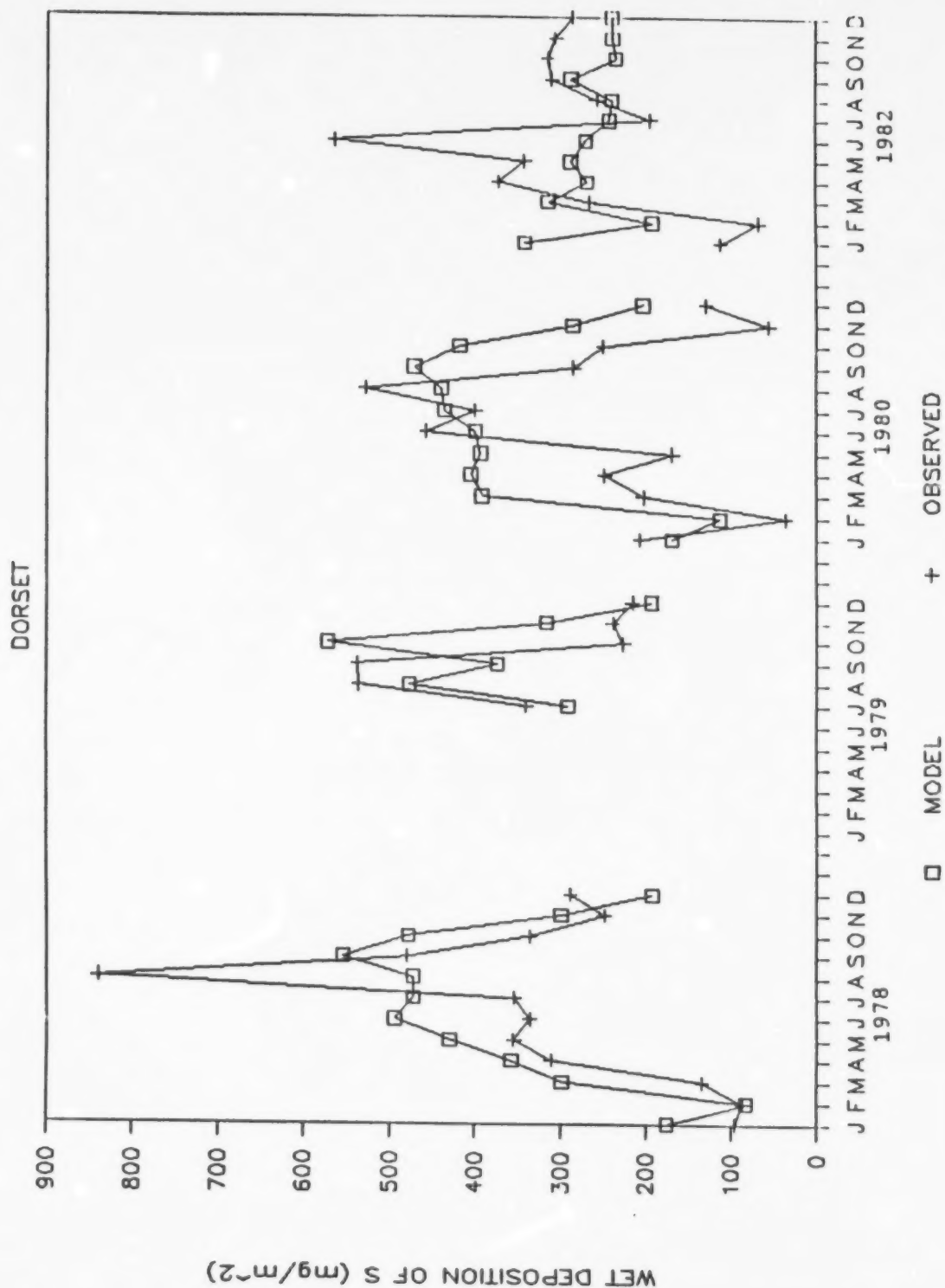


Figure A.5

Comparison between predicted and observed wet sulphate deposition at Chalk River, Ontario

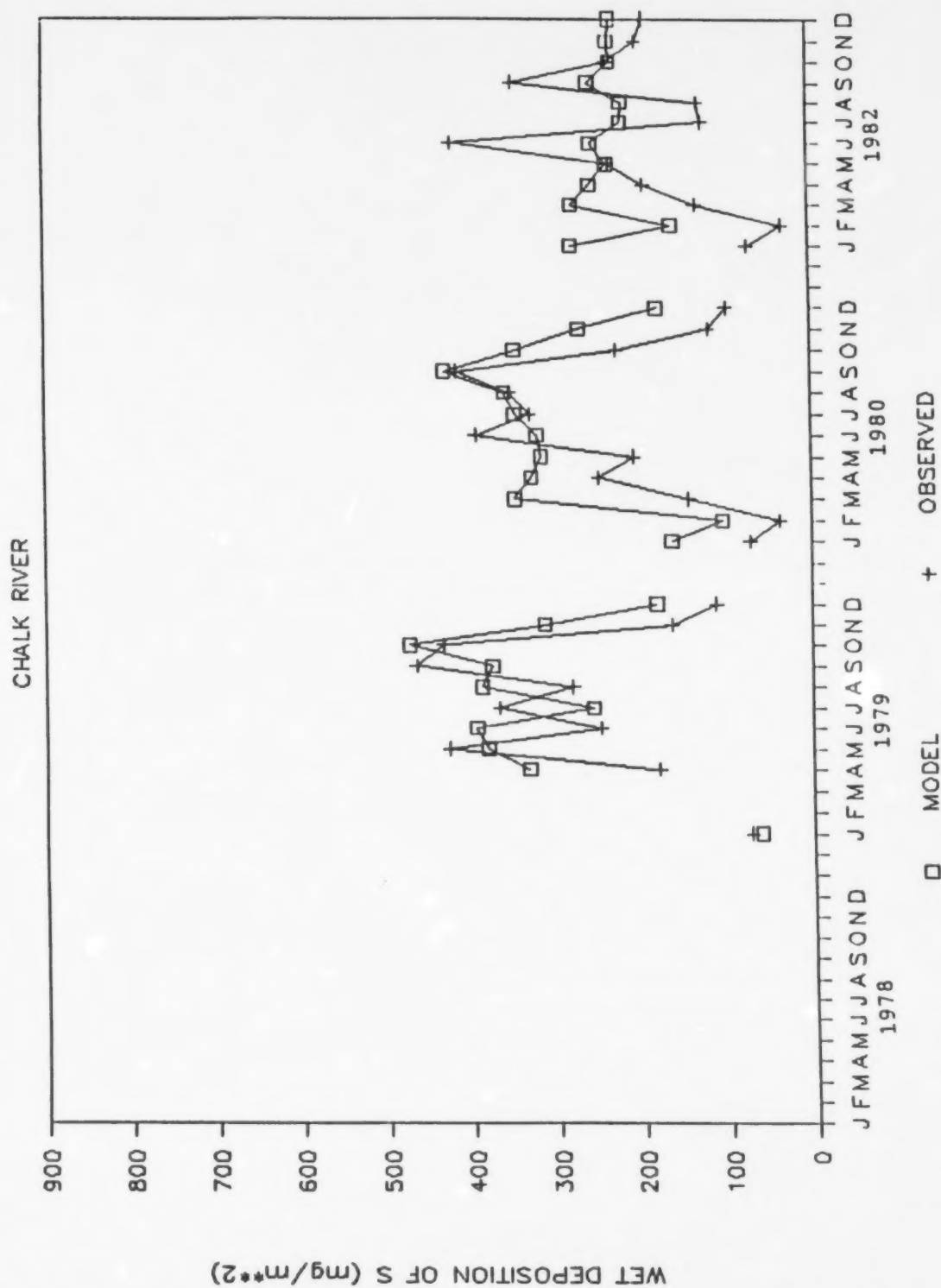


Figure A.6

Comparison between predicted and observed wet sulphate deposition at Kingston, Ontario

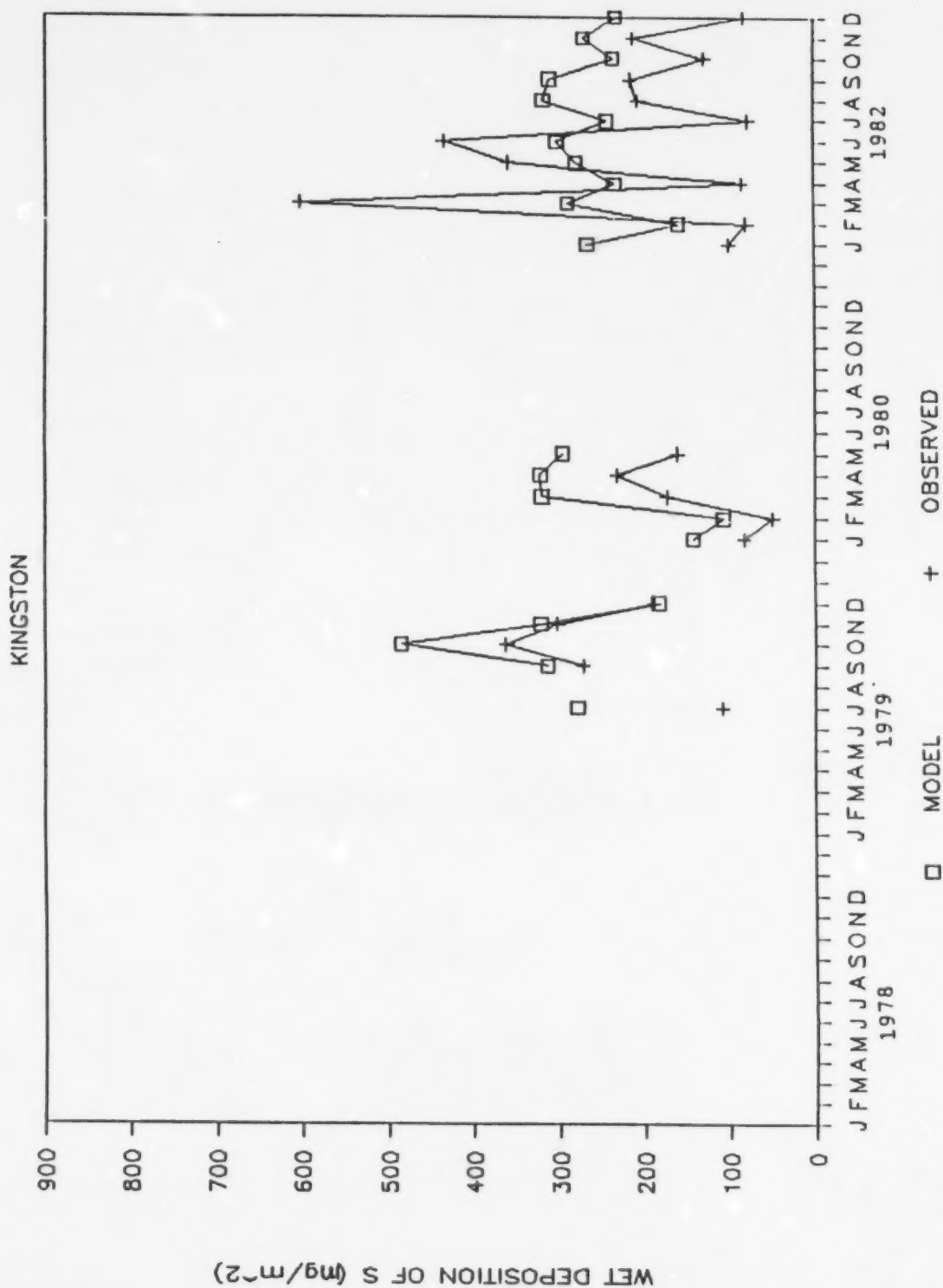


Figure A.7

Comparison between predicted and observed wet sulphate deposition at Pennsylvania State University, Pennsylvania

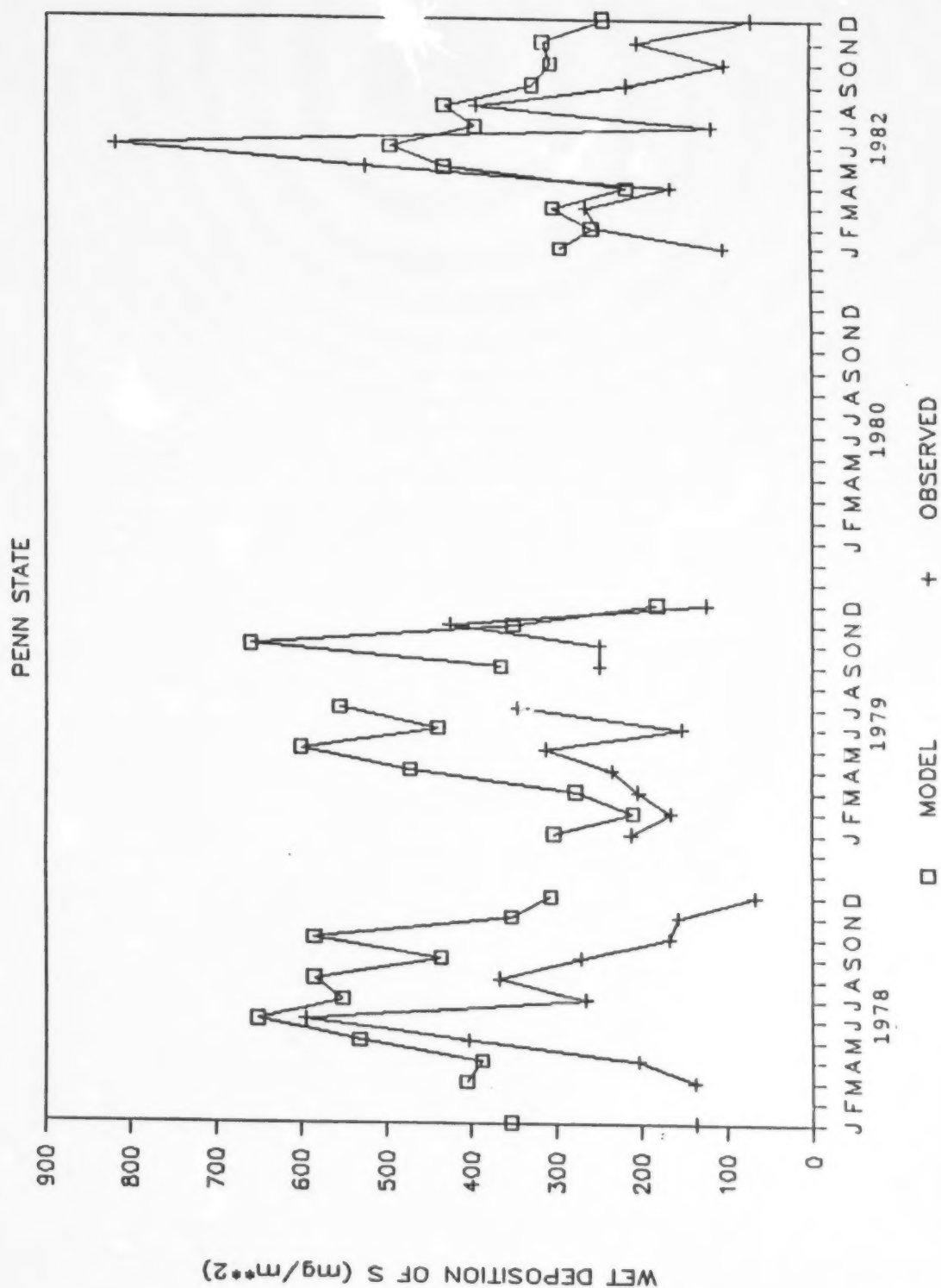


Figure A.8

Comparison between predicted and observed wet sulphate deposition at Whiteface Mountain, New York State

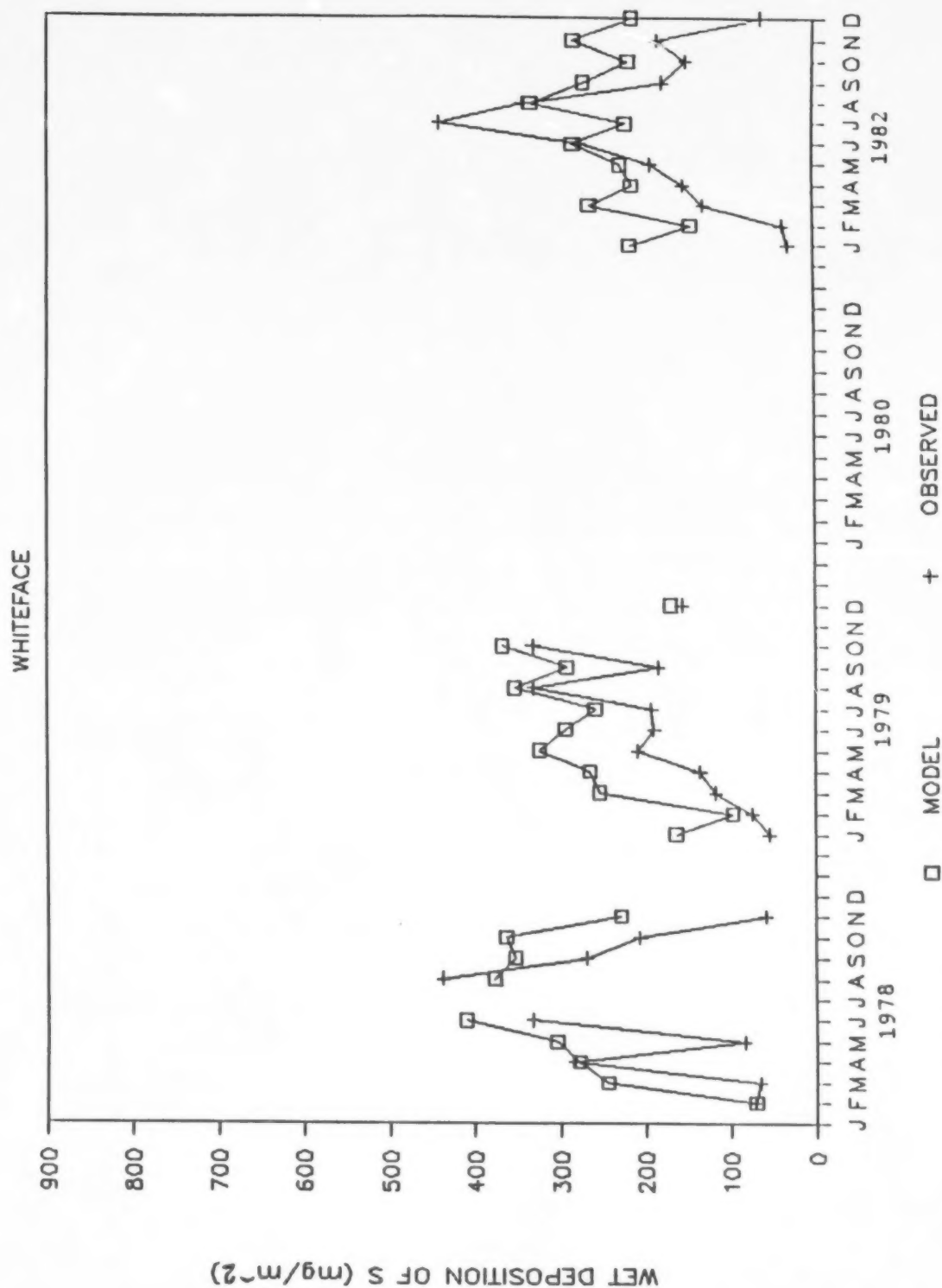


Figure A.9

Scatter diagram of predicted and observed monthly
wet sulphate deposition (1978-82)

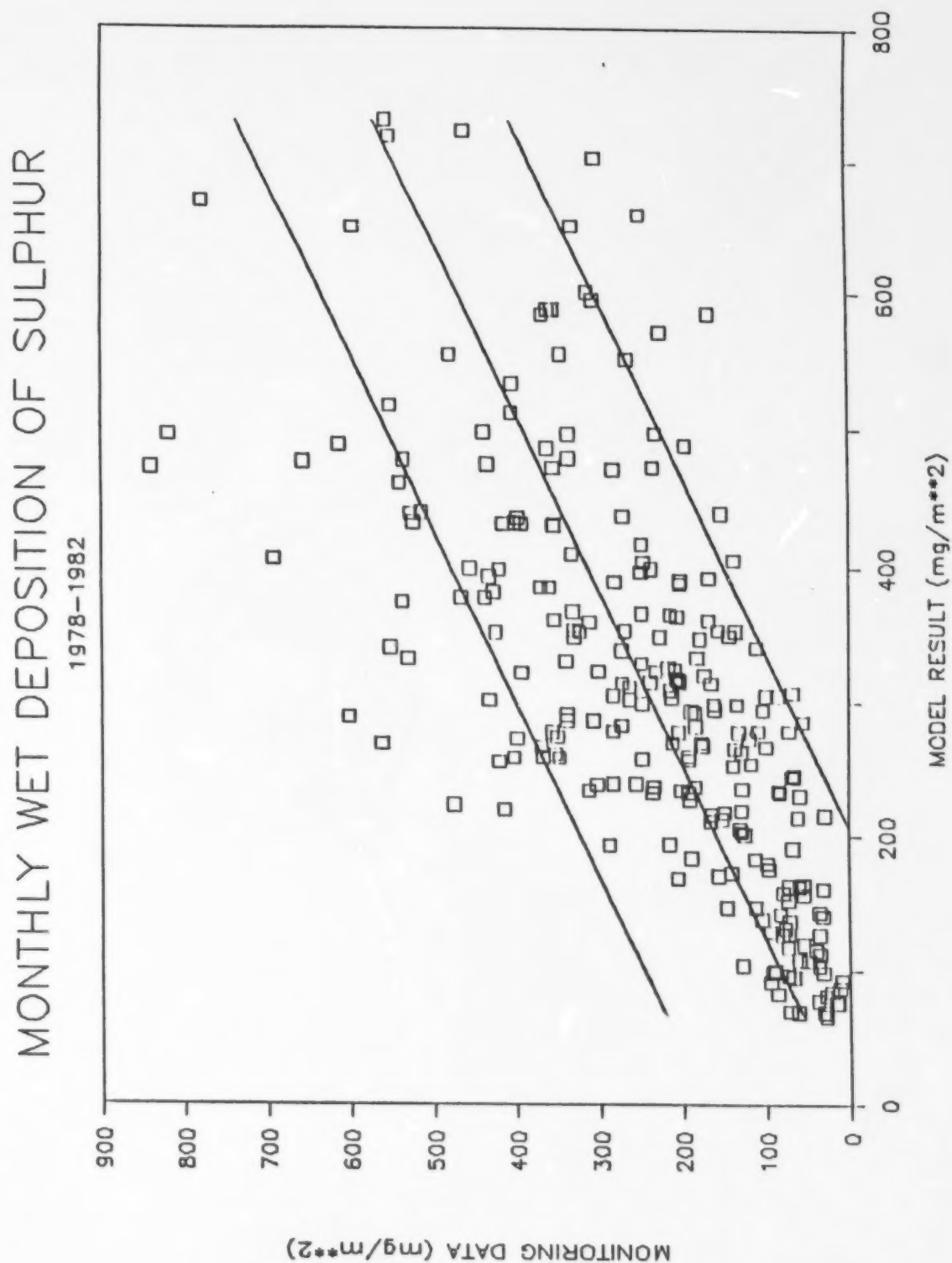
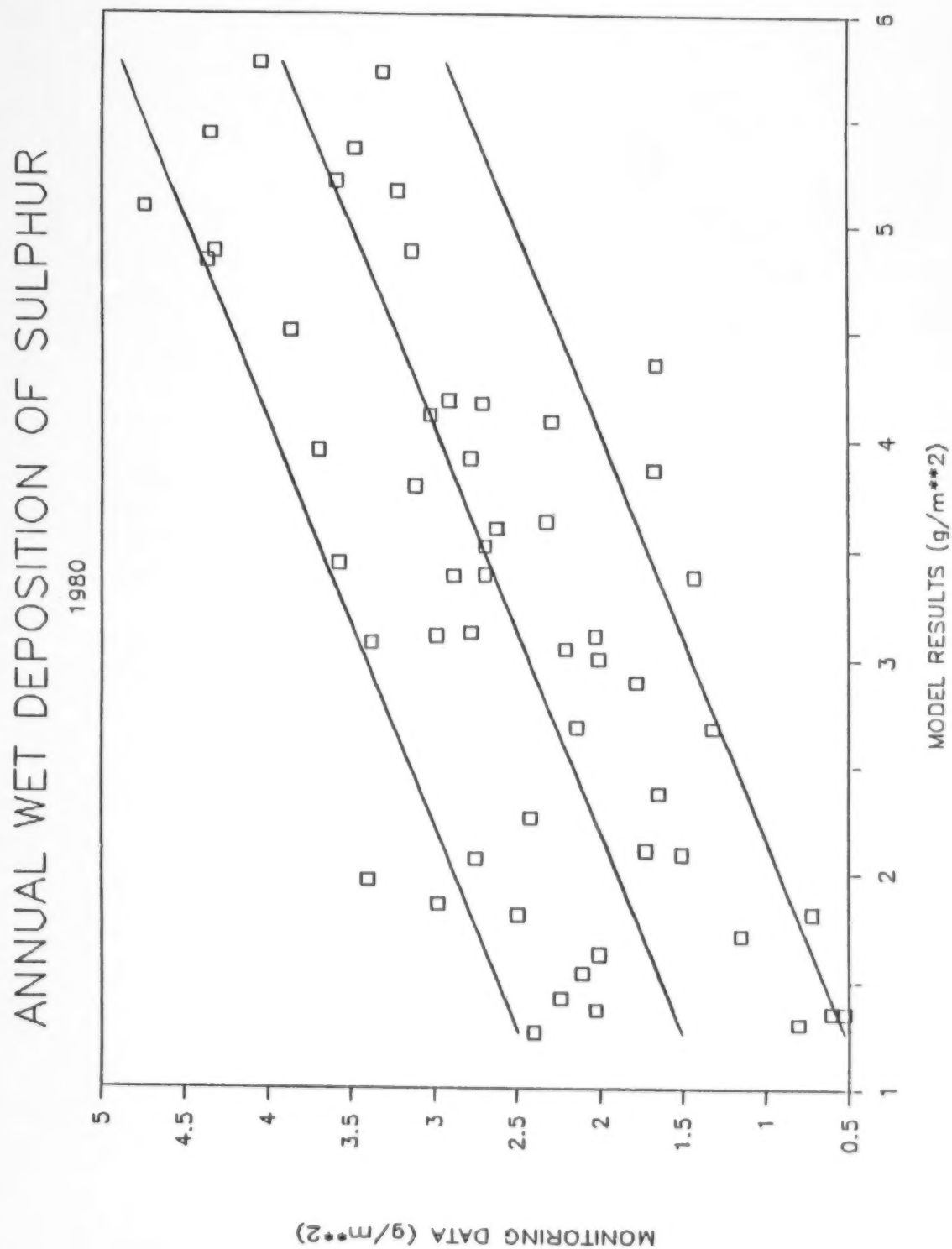


Figure A.10

Scatter diagram of predicted and observed annual wet sulphate deposition in 1980



APPENDIX B

ONTARIO HYDRO'S VERSION OF FISHER'S STATISTICAL LONG-RANGE TRANSPORT MODEL

In Ontario Hydro's version of Fisher's long-range transport (OHLRT) model, we consider a source emitting SO_2 or NO_x into a horizontal air stream moving with a velocity u past the source. The emissions are distributed throughout the atmosphere by advection with the wind, and by dispersion in the vertical and crosswind directions. Vertical mixing is assumed to take place in a uniform layer of height a (the mixing layer), with the rate of mixing defined by an eddy diffusivity. It is assumed that no material penetrates above the mixing layer. It is also assumed that the mixing layer is effectively in a steady state. Diffusion in the downwind direction is presumed negligible compared to horizontal advection. Vertical winds are assumed to be unimportant. Diffusion in the vertical is assumed independent of crosswind diffusion.

Dry deposition, chemical transformation and wet deposition are included in OHLRT. Dry deposition is handled as a lower boundary condition. For chemical transformation, it is assumed that a fraction of the emissions (primary pollutant) is actually emitted as the secondary pollutant (chemically transformed primary pollutant) or is transformed at an accelerated rate shortly after emission. A rate constant k is assumed to apply thereafter. Wet deposition is handled as a volume sink term. OHLRT is discussed in detail in Wright (1989).

The model's emission and deposition grid is a 25×25 grid with grid cells 127 km on each side. It covers the northeastern United States and southeastern Canada and is a subgrid of the Canadian Meteorological Centre (CMC) grid system. Emission rates are expressed as kilotonnes SO_2 and NO_x (as NO_2) emitted within each grid square for the time period being considered.

OHLRT uses long-term statistical distributions of wind speed, wind direction, dispersion categories and rainfall. Several different climatic regions may be defined. For each region, meteorological classes, a wind rose and mean lengths of wet and dry periods are specified. A meteorological class consists of an average wind speed, mixing height, eddy diffusivity and weighting factor.

The chemical parameters which must be specified to calculate average deposition fluxes of nitrogen compounds are the dry deposition velocities for NO_x and NO_3 , the transformation rate coefficients and initial fractions converted.

Model performance was measured using 1980 emissions and meteorological data as input. Calculated wet deposition fluxes of nitrate were compared to monitoring data from the networks described in Appendix A. Model results are plotted against observed data in Figure B.1. The model predicts within a factor of 2 approximately 75% of the time. The correlation coefficient indicates that the OHLRT model explains 77% of the variance in the wet deposition of NO_3 .

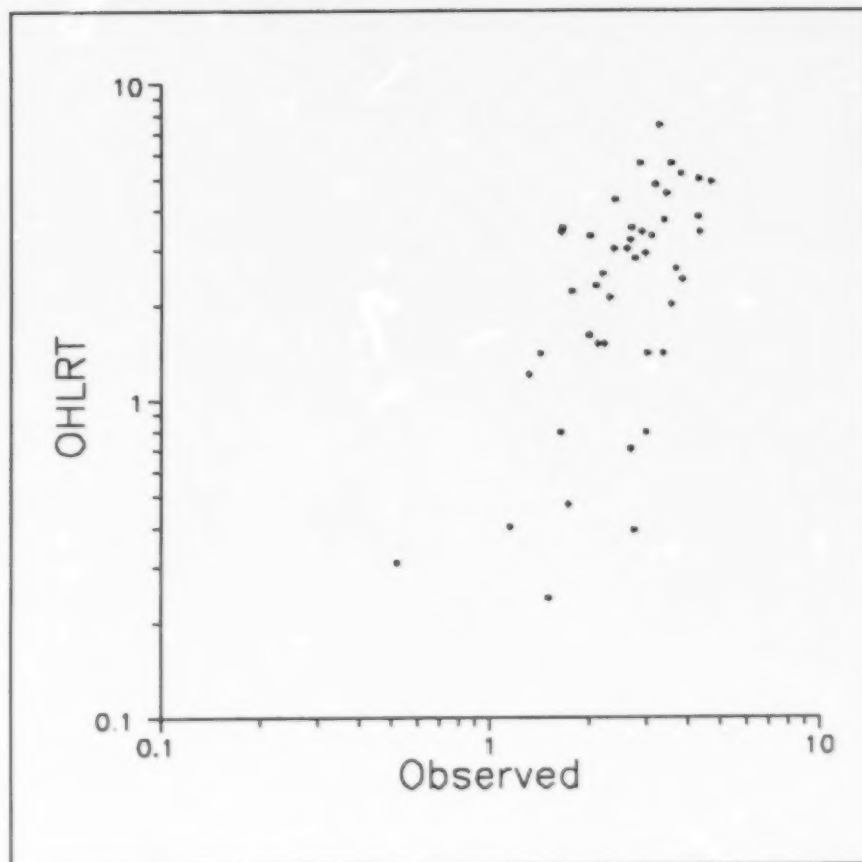


Figure B.1
Model (OHLRT) results vs. Observed data
NO₃ Wet Deposition, 1980 (g m⁻²)

APPENDIX C

SHORT-RANGE TRANSPORT MODEL

The short-range transport model used to calculate air quality and dry deposition of various pollutants in the vicinity of the three larger Ontario Hydro fossil-fuel-fired power stations (ie, Lambton, Nanticoke, Lakeview) was a modified version of the modelling package provided by the Ontario Ministry of the Environment, known as the dispersion model of the Ontario Clean Air Program Discussion Paper. The Clean Air Program (CAP) calculates air concentrations of a pollutant through three meteorological condition-dependant sub-modules. The meteorological conditions are classified into convective, neutral and stable cases, respectively, according to the sign and absolute value of the surface heat flux. For detailed specifications and parameterizations of the model, readers are referred to the green paper issued by the Ontario Ministry of the Environment (MOE, 1987).

In the present study, the model was implemented over a 21 by 21 grid array with a grid size of 3 km and with an emission source located in the centre of the array. This design enabled us to obtain a detailed description of air concentration of a pollutant in the vicinity of the source on an hourly basis. To represent the shoreline settings of the Nanticoke and Lakeview power stations, the shoreline fumigation model of the Ontario Ministry of the Environment (Misra, 1980; MOE, 1987) was added to the CAP modelling package. In doing this, several difficulties were overcome. First, we calculate A, the thermal internal boundary layer (TIBL) parameter, using equations similar to the one derived by Raynor et al (1975), based on physical and dimensional considerations, and the one derived analytically by Venkatram (1977):

$$A = \frac{U_*}{U_m} \left[\frac{2(\theta_L - \theta_w)}{\gamma} \right]^{1/2}$$

where U_* is the friction velocity over land, θ_L and θ_w are the potential temperatures over land and water, respectively, and γ is the lapse rate over water. In the calculation, we set γ equal to the adiabatic lapse rate, because of a lack of measurements. For the water surface temperature, we use the near-shore water temperature data, available from the Design & Development - Generation Division of Ontario Hydro, for Nanticoke and the intake temperature data, available from the Central Production Services Division of Ontario Hydro, for Lakeview. Second, the value of the convective velocity scale W_* , calculated in the original Regulation 308 code, is passed onto the fumigation module. The reason for doing this lies in the fact that W_* is proportional to the cube root of the product of surface heat flux and TIBL height. Since the TIBL height increases with inland distance and the surface heat flux decreases with inland distance, W_* can be regarded as essentially invariant (Venkatram, 1977; Misra, 1980).

In order to get distributions of dry deposition of SO_2 , NO_x and various trace pollutants, methods for computing atmospheric resistances (Droppo and Doran, 1983) and surface resistances for particles with various sizes (Sehmel and Hodgson, 1978) were adopted.

Meteorological data for 1983, suitable for the Lambton station, were compiled and provided by the Ontario Ministry of the Environment. Data for the other two stations (Nanticoke and Lakeview) for 1983 were prepared by the Environmental Science Section of Ontario Hydro Research. The mixing heights were derived from Buffalo radiosonde temperature profiles following the method of Holzworth (1967). Wind speed, wind direction, temperature, cloud coverage and snow coverage were taken from the Jarvis meteorological tower, and Simcoe Airport, for Nanticoke and from the Evans meteorological tower, and Toronto Island Airport, for Lakeview.

To assess the performance of the short-range transport model, we compared the modelled 1983 annual average ground-level concentration of SO_2 against the observed data obtained by Ontario Hydro's Nanticoke air quality monitoring network. The observed annual mean concentrations of SO_2 at each sampling site, attributable to the Nanticoke station were obtained by subtracting background values, corresponding to the lowest value from all sites in each wind direction, from reported annual values at monitoring sites, followed by a wind direction frequency-weighted averaging procedure. The comparison is shown in Table C.1. The correlation coefficient between these two sets of data is 0.69 which means that the model explains 48% of the variance in the observed annual ground level concentration of SO_2 .

TABLE C.1
COMPARISON BETWEEN MODELLED AND MEASURED
ANNUAL GROUND-LEVEL SO_2 CONCENTRATIONS (ppb)
NANTICOKE TGS, 1983

Monitoring Sites	Measured	Modelled
NO7	2.09	2.05
N15	0.74	1.06
NNE05	3.21	1.93
NNE09	1.05	1.57
NNE16	2.49	1.71
NNE20	0.72	1.62
NE19	0.98	1.21
ENE11	1.79	1.26
ENE18	1.72	1.02
E05	2.60	1.92
W13	0.81	0.90
WNW03	0.84	1.15
WNW20	0.82	0.72
NNW08	1.72	1.08
NNW11	0.81	0.98
NNW15	1.70	0.89

APPENDIX D

THE CAPMON MONITORING NETWORK

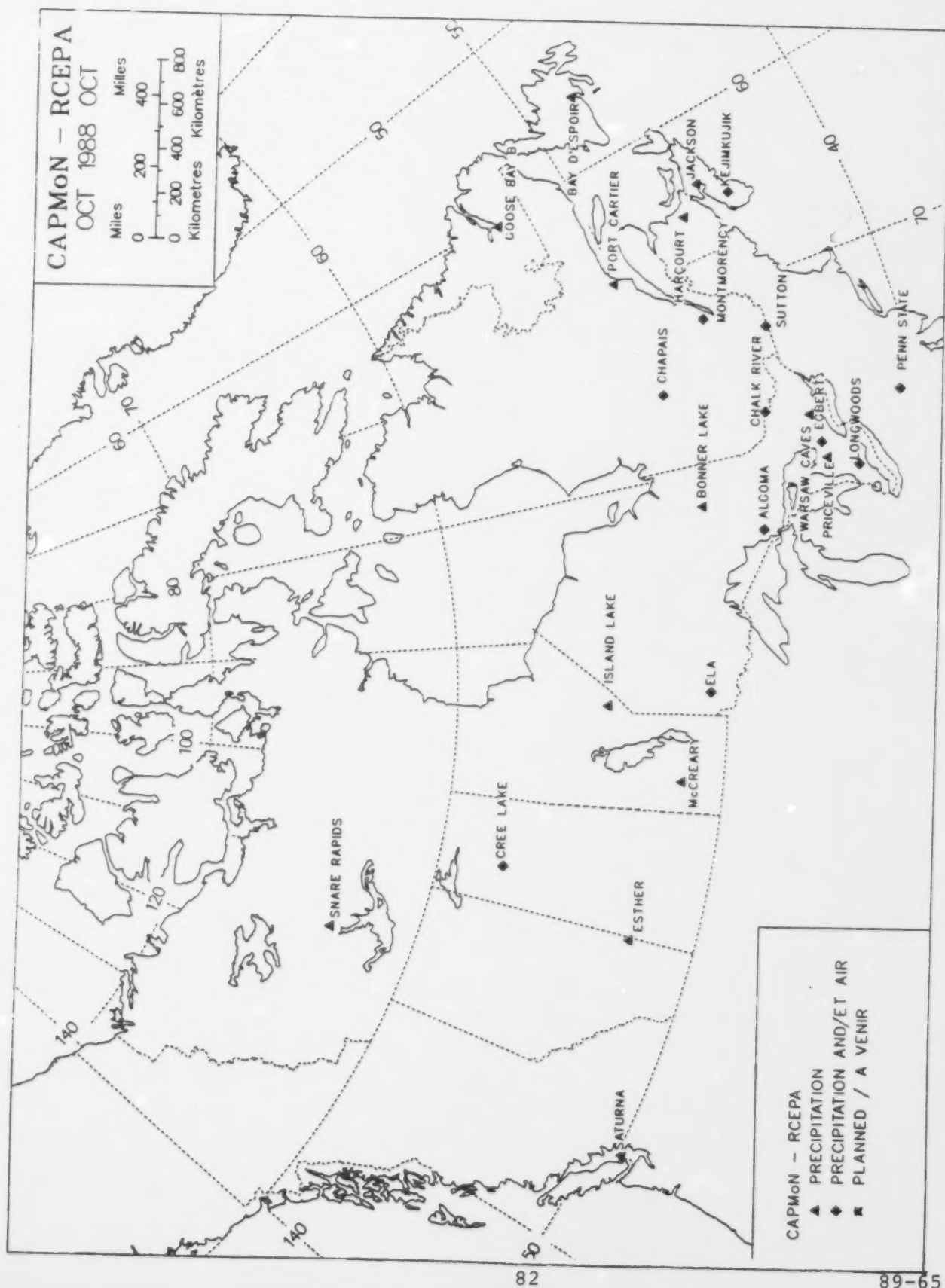


FIGURE D.1
LOCATION OF CAPMoN MONITORING STATIONS